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DEPARTMENT OF THE INTERIOR

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REVIEW OF LITERATURE ON EFFECTS OF BREATHING DUSTS WITH SPECIAL REFERENCE TO SILICOSIS

PART II-A

CHAPTER 4. PREVENTION OF DUST DISEASES (SECTIONS 1 AND 2)

BY

D. HARRINGTON AND SARA J. DAVENPORT

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REVIEW OF LITERATURE ON EFFECTS OF BREATHING DUSTS WITH SPECIAL REFERENCE TO SILICOSIS[1]

PART II-A

By D. Harrington[2] and Sara J. Davenport[3]

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This circular presents Part II-A of a review of the literature on the prevention of dust diseases; it deals with the principal factors producing pulmonary pathology and methods of determination of dust in air. Part II-B will contain data on the engineering and medical control of dust diseases.

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CHAPTER 4. PREVENTION OF DUST DISEASES

Introduction

As no cure is known for silicosis after it has developed, prevention is the only effective remedy. There are two main lines of approach to the problem of dust-disease prevention in industry - the engineering, through control of dust production, and the medical, through selection of workers by examination; success probably depends upon a combination of the two.

Hatch (146) considers the following measures essential to a complete, well-balanced program of control of the dust hazard in industry:

1. Selection of workers by means of physical examinations in order especially to eliminate those with tuberculosis and other disorders of the respiratory system.

2. Reduction of the dust concentration below the standard of permissible dustiness through adequate means of dust control and good housekeeping.

3. Limiting the frequency and duration of employment in the dusty occupations, thus reducing the rate of deposition of dust in the lungs.

4. Routine measurement of the effectiveness of the dust-control program by means of periodic medical examinations and dust surveys.

Of these reduction in dustiness is the most direct in its effect and is fundamental to any program of control. Hatch (146) emphasizes, however, that present-day standards of safety are only estimated values and reduction in dust exposure below the estimated threshold value does not give absolute assurance of complete control of the disease. Moreover, a potential hazard always exists in basically dusty industries, and a constant guard therefore must be maintained. Workers should be selected by physical examination to insure maximum resistance against the action of dust in the lungs. The employment of workers already injured by previous dust exposure thus would be largely eliminated. Routine determination of dust concentrations provides a measure of operation of the dust-control system, but the efficacy of the control program must be measured by periodic medical examination, since only by this means can the presence or absence of silicosis be determined. An inadequate control program thus can be strengthened in time to arrest the widespread development of the disease.

Section 1. - Principal Dust Factors Producing Pulmonary Pathology

The principal factors now thought to determine whether exposure to dust will produce pulmonary pathology are nature of the dust, particle size, quantity of the dust dispersed in the atmosphere, and length of exposure. In

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general, it has been held that, other factors being equal, the harmfulness of a quartz-containing dust is in direct proportion to its quartz content. Apparently, then, it is important to ascertain the exact mineralogical composition of any dust under investigation.

Every mineral possesses certain characteristic properties that separate it from other minerals of similar appearance when viewed under the polarizing microscope. These diagnostic characteristics are supposed to persist even to the grains of smallest size; with patience, therefore, the percentage of the various mineral constituents of a dust can be determined (147).

Silica Dust

Free silica or quartz has been considered the outstanding dust factor in industries with excessive mortality from dust diseases. The following summary of information on the chemical properties, occurrence, and industrial uses of silica is taken from A Review of Silicosis by Adelaide Ross Smith (148).

Chemical properties of silica.- Silica has the chemical formula SiO_2, indicating that it is a combination of the element silicon (Si) and oxygen (O). It occurs alone in the "free" form and, as such, is variously known as silicon dioxide or "free" silica. In combination with other elements it is known as "combined silica", but this report is concerned with free silica especially because in this form it causes more damage to the lungs than when it is in the combined state.

Free silica (silicon dioxide) may be either crystalline or noncrystalline (amorphous) in structure. Crystalline silica, which is usually quartz, is a white or colorless, extremely hard substance ordinarily with a specific gravity of 2.66. When heated for a long time at about 1,000° C. it forms a second variety known as "tridymite" with a specific gravity of 2.33; a third variety, cristobalite (specific gravity 2.34), occurs when quartz is heated for periods not long enough to form tridymite. Noncrystalline (amorphous) silica occurs as a fine white powder.

Silica assumes the vitreous, molten form more easily than any other mineral substance, melting to colorless quartz glass in the oxyhydrogen blowpipe at about 1,600°. The coefficient of thermal expansion of quartz glass is very small, so that it possesses in a high degree the property of being able to withstand rapid cooling without cracking.

Silica is chemically inactive at ordinary temperatures but at high temperatures acts as an acid anhydride and combines with the bases and many metallic oxides to form silicates. When soluble alkaline silicates are treated with acids silicic acid, an amorphous gelatinous substance, is obtained. This is soluble in water and acids and is readily dissolved by dilute solutions of alkali hydroxides and carbonates.

Occurrence of silica in nature.- Silica is one of the most common minerals. In one form or another it constitutes approximately 60 percent of the earth's crust and forms whole mountain ranges in certain countries.

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Examples of free silica in the pure crystalline form are quartz and rock crystal, but many other minerals whose essential composition is quartz have been changed in color or form by the addition of small amounts of other substances, usually oxides of other elements. Many of these are used chiefly for ornaments and jewelry; but some, such as buhrstone and flint, have important industrial uses as well. These quartz rocks include the following: Agate, aventurine, amethyst, bloodstone, brazilian pebble, buhrstone, carnelian, cat's-eye, chalcedony, chert, cairngorm, chrysoprase, certine, flint, hairstone, hyalite, jasper, jaspilite, lydian stone, milk quartz, needlestone, onyx, opal, plasma, phrase, rose quartz, sard, smoky quartz, and tiger's-eye. Common rocks containing a high proportion of free silica are: Sandstone, essentially grains of quartz with some feldspar, mica, and other materials added, quartzite, a product of sandstone; ganister, a sedimentary rock with a very high percentage (about 98 percent) of free silica; granite, composed essentially of quartz and feldspar, containing 25 to 35 percent of free silica; and pegmatite, a form of granite. Ordinary sand is almost entirely quartz.

Amorphous (noncrystalline free) silica forms opal and is associated with quartz in certain other stones, such as chert, flint, and chalcedony. It is represented chiefly by diatomaceous earth and tripoli or rottenstone.

Diatomaceous earth is a soft, earthy rock composed of the skeletons of small aquatic plants resembling chalk in appearance. It can hold four times its weight of water and is a poor conductor of heat, sound, and electricity. Tripoli is a porous rock which results from the natural decomposition of sandstone.

Combined silica (silicates) occurs in almost every rock species and forms the essential substance of such common materials as clay, mica, feldspar, and slate.

Industrial uses of silica.- Silica has many properties of industrial value; Hardness; resistance to solution (even in acid), heat (under some conditions), and temperature changes; and crystalline and decorative properties. In the amorphous form it is also valuable as a filtering medium and nonconductor.

It is used in a variety of different forms, in the massive form both roughly broken and cut to different sizes and shapes; in the original condition as pebbles or as grains; crushed to a coarsely granular form or ground to a fine powder. Its chief uses and corresponding forms have been tabulated by Smith (148) from Ladoo as follows:

> Abrasive uses, in scouring and polishing soaps and powders - quartz, quartzite, flint, chert, sandstone, sand, tripoli, and diatomaceous earth, all in finely ground state; in sandpaper - quartz, quartzite, flint, sandstone, and sand, coarsely ground and closely sized; in sand-blast work - quartz, quartzite, sandstone, and sand, crushed into sharp angular grains uniform in size; metal buffing, burnishing, and polishing - ground

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tripoli and other forms of ground silica; for sawing and polishing granite - sharp, clean sand graded into various sizes; as whetstones, grindstones, buhrstones, pulpstones, oilstones - massive sandstone from very fine- to moderately coarse-grained; tube-mill lining - chert, flint, and quartzite in dense, solid blocks; lithographers' graining sand - medium to fine sand or rather coarsely ground silica and tripoli; tube-mill grinding pebbles - rounded flint pebbles; in tooth powders and paste - various forms of pure silica finely ground; wood polishing and finishing - all forms of silica ground to medium fineness. Refractory uses, in making silica fire brick and other refractories - fairly pure quartzite known as ganister, not less than 97 percent SiO_2 nor more than 0.40 percent alkalies, tightly interlocking grains desired. Metallurgical uses, in making silicon, ferrosilicon, and silicon alloys of other metals, as copper - moderately pure sand, massive crystalline quartz, sandstone, quartzite, or chert; as a flux in smelting basic ores - massive quartz and quartzite; foundry-mold wash - ground sandstone, quartz, and tripoli; foundry parting sand - fine sand and ground tripoli. Chemical industries, as a lining for acid towers - massive quartz or quartzite; as a filtering medium - massive diatomaceous earth and tripoli, sand, finely granular quartz or quartzite, finely ground tripoli, and other forms of silica. In the manufacture of sodium silicate - pure pulverized quartz sand, pure tripoli, and diatomaceous earth. In the manufacture of carborundum - pure quartz sand. Paint, as an inert extender - finely ground crystalline quartz, quartzite, and flint, also finely ground sandstone, sand, and tripoli. Mineral fillers, as a wood filler - finely ground crystalline quartz, quartzite, flint tripoli, and other types of ground silica. In fertilizers and insecticides - finely ground crystalline quartz, quartzite, flint, tripoli, and other types of ground silica. As a filler in rubber, hard-rubber pressed and molded goods, phonograph records - finely ground silica of all types. In road asphalt surfacing mixtures - finely ground silica of all types. Ceramic uses, in the pottery industry as an ingredient of bodies and glazes, flint, tripoli, and chert (amorphous silica preferred), also all other forms of very pure silica, all finely ground. Building stone - cut granite and sandstone. Monuments, paving blocks - cut granite. In the manufacture of ordinary glass - pure quartz sand; in the manufacture of fused-quartz chemical apparatus, as tubes, crucibles and dishes - very pure massive quartz preferred. Decorative materials, in the manufacture of gems, crystal balls, table tops, vases, statues - rock crystal, amethyst, rose quartz, citrine quartz, smoky quartz, chrysoprase, agate, chalcedony, opal, onyx, sardonyx, jasper. Insulation, heat insulation for pipes, boilers, furnaces, kilns - massive and ground diatomaceous earth; sound insulation in walls, between floors - massive and ground diatomaceous earth. Structural material, sand-lime brick - moderately pure, sharp, angular sand, preferably finer than 20-mesh, together with a small percentage of finely pulverized silica, optical quartz, for the manufacture of lenses and accessories for optical apparatus - clear, colorless, flawless rock crystal or massive crystallized quartz.

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Sericite.- In 1926 Mavrogordato (149) remarked that -

> The increasing use of the term "silicosis" implies the recognition that in industry this disease is particularly related to inhalation of dust of free silica (SiO_2); in fact it is doubtful if it occurs apart from free silica, or, anyhow, the intractable silicates, for example, sericite.

The mention of sericite by Mavrogordato is interesting in connection with the relatively recent statement by Jones (150) that sericite, not silica, causes silicosis. He explains the circumstances which caused him to reach this conclusion:

> During the last 20 months I have had occasion to visit a number of collieries in the anthracite district of the South Wales coal field with the object of collecting, from the former working places of underground employees who had contracted silicosis in the course of their employment, samples of rock which could be proved to come under the category of "silica rock" as defined in English law, for the purpose of compensation under the Silicosis Schemes. It should be explained here that, whereas under your (South African) mining law an employee who is certified as having contracted silicosis in the course of his employment in your gold mines, receives compensation without further legal proceedings, English law, on the other hand, demands proof, in the case of underground workmen in collieries, that the employee has been working in "silica rock", that is, in quartz, quartzite, sandstone, gritstone, or chert. In the majority of cases I was able to find samples of rock that fulfilled the legal definition of "silica rock", but in some, even when post-mortem examination had revealed silicosis and where the former working places of the deceased were accessible, it was not possible to find rock of the type included in the Silicosis Scheme. These cases, and there were several of them, naturally aroused my interest, for they appeared to make clear the possibility that rocks other than those included in the Silicosis Scheme could give rise to dangerous dusts. I decided to investigate the matter.

Jones (151) summarized the results of his investigation as follows:

> The result of these investigations on the mineral residues obtained from 29 silicotic lungs and of the examination of the rocks and materials which gave rise to the inhaled dusts causing these cases of silicosis lead to the following conclusions:
>
> 1. The bulk of the mineral residues obtained from every silicotic lung investigated by the author consists of minute fibers of the mineral sericite, a hydrated silicate of aluminium and potassium known also as "secondary white mica." This mineral is abundantly present also in all the rocks and materials which gave rise to the inhaled dust, and it is present in these rocks and material in minute fibers and scales of the size it is found in the residues and also in the lung tissue.

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2. Silica in the uncombined state, as quartz, is also present in these residues as relatively coarse and fine grains; it occurs, however, in amounts subordinate to sericite. Especially is this so with regard to the small number of quartz particles, as compared with the countless fibers of sericite.

3. One relatively large grain of quartz, measuring 10 by 8 by 5 microns, such as is found in the residues, is equal in volume to 800 fibers of sericite measuring 2 by 0.5 by 0.5 microns and contributes as much silica in the chemical analysis of a residue as would 16,000 fibers of sericite. This would appear to be out of all proportion to the silicotic effect of one such quartz grain in the bronchi and bronchioles, compared with the effect in the alveoli of hundreds of fibers of sericite.

4. Silica in the uncombined state, as quartz, is not the chief cause of silicosis in these and certain other cases. This appears to be conclusively established, it is submitted here, by the following facts: (a) The amount of quartz and the size and form of the quartz grains in the sandstones occurring in the underground working places in the Scottish coal fields and in the South Wales coal fields are alike. The latter sandstones give rise to dust that has caused scores of cases of silicosis, whereas no authenticated case of silicosis has been produced in the Scottish coal fields. (b) The gold-bearing quartz conglomerate of South Africa gives rise to dust that has caused thousands of cases of silicosis; the gold-bearing quartz rock of the Kolar golf field, India, contains more quartz than the South African rock and yet produces dust that has caused no case of that disease. (c) No quartz-bearing rocks investigated by the author are known to have given rise to silicosis-producing dust except those which also contain abundance of fibrous aggregates of sericite or of fibrous silicate minerals, loosely held together and easily freed into the atmosphere when the rock is drilled and blasted. (d) Rocks which contain a relatively small percentage of quartz (well below the minimum amount in the rock types named in the Silicosis Schemes under English law), but which do contain fibrous silicate minerals such as sericite and sillimanite - as, for example, at Broken Hill mines, New South Wales - produce dust that has caused a large number of silicosis cases.

5. These investigations are not concerned with the pathological condition produced by the minerals in the lungs. Whether they merely act as mechanical irritants causing the growth of fibrous tissue, as advocated by some well-known authorities, or induce chemical changes, as maintained by certain eminent pathologists, is a question entirely beyond the province of the author. His conclusions do not militate against either theory; on the contrary, they provide the former school with evidence of the presence in the lungs of thousands of acicular fibers that presumably could act as mechanical irritants and the latter school with evidence of the presence of silicate minerals less stable than quartz and which, because of their physical form, expose far greater surface to volume for any chemical action than do the more compact grains of quartz.

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6. Lastly, it is submitted that it is mainly the presence in the exploited rocks and materials of fibrous minerals, be they sericite, sillimanite, tremolite, etc. (or a fibrous form of free silica in chert, or of a fibrous rock as in pumice), in aggregates which, during the impact of drilling, blasting, or crushing, become freed into the atmosphere as individual fibers, that enables sufficient material in course of time to enter the lungs to cause silicosis. It is not suggested that sufficient minute particles of quartz could not, under any circumstances whatever, enter the lungs to cause silicosis, although the cases hitherto investigated appear to show conclusively that they have not done so; but it is maintained that the fibrous minerals hasten the process so very considerably that their presence in the exploited rocks and materials is of far greater importance in causing this disease than is the presence of quartz.

The statement by Jones that sericite rather than silica dust is the cause of silicosis aroused considerable discussion among those interested in the question. In September 1933 Jones (152) presented a paper before the Chemical, Metallurgical, and Mining Society of South Africa in which he said:

I submit, therefore, that the mineral residues I obtained from silicotic lungs (and this applies to all those I have so far investigated) show definitely that it is not quartz, or any kind of free silica, that forms the bulk of these residues; and I suggest that silicosis is not mainly due to free silica, as has hitherto been accepted, but to silicate minerals occurring in the form of minute fibers loosely held together in the rocks so that, during handling, drilling, and blasting, they are readily freed into the atmosphere and inhaled into the lungs. * * *.

It is clear, therefore, that hitherto no acceptable explanation has been given why the inhaled dust of your South Africa quartz-bearing rock is so extremely dangerous in its silicotic effect and why the dust of the Indian rock, with still more quartz, has not caused a single case of silicosis. The real explanation I submit, is simple: Whereas in the South African rock there are, between the quartz pebbles and quartz grains, aggregates of minute acicular fibers of sericite, hundreds of which fibers can be seen in microscope sections of this rock, such acicular fibers are absent from the Kolar quartz rock or very rare. The quartz grains in the Kolar rock are interlocking: there is no fibrous mineral to be seen between the sharp boundaries of the individual grains. Between the quartz pebbles and the quartz grains in the "banket", acicular crystals of sericite are very abundant; in fact, sericite ranks next to quartz as the most common mineral in your gold-bearing quartz conglomerate. It is not suggested here that all the sericite present is in fibrous form; much of it is in the form of minute scales, but the point is that countless fibers of this mineral do occur throughout this rock. * * *.

There is one other outstanding case which will be referred to here because it has features of peculiar interest; it is that of the Broken Hill mines, New South Wales, Australia. Many cases of silicosis have

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been diagnosed amongst the Broken Hill miners where "in 8 years 160 mine workers were withdrawn as suffering from simple silicosis" and where in a similar period "of 101 men classified as suffering from silicosis plus tuberculosis there were living only 15; 86 percent had died." The amount of free silica in the Broken Hill ore (and the ore bodies, be it noted, are very wide) varies from 1.62 to 17.73 percent; and in the "country rock" it averages under 20 percent free silica. In some of the mining blocks at Broken Hill, where cases of silicosis have occurred, there is no rock which could be included under any of the types of rock named in the Silicosis Schemes in English law, yet dust has been produced that, as stated, has given rise to scores of cases of this disease; that in itself is a fact full of significance. At Broken Hill, however, occurs a rock known as "sillimanite gneiss", in which the aluminium silicate mineral, sillimanite, occurs sometimes in large crystals but generally as minute fibers; in fact the alternative mineralogical name of sillimanite is "fibrolite" because it so commonly occurs in fibrous form. Sericite is also abundantly present in some of the Broken Hill rocks. Here then we have rocks low in their content of free silica, but containing fibers of sericite and sillimanite, which produce dangerous dusts.

Attention was drawn to the low content of free silica in the Broken Hill ore and adjacent rocks by Dr. R. R. Sayers in 1925 and by Drs. Charles Badham and W. E. George of New South Wales at the International Conference in 1930. It is of particular interest to note also that at the Conference the possibility that silicates may have played a role in the causation of silicosis was not entirely overlooked although it seems clear from the definition accepted at the final sittings (that the disease was caused by silica in the uncombined state) that their effect was underestimated. Dr. E. L. Middleton pointed out that "silicates would, sooner or later, have to be studied systematically as the cause of pulmonary disease in industry. There is abundant evidence already that the silicates cannot be regarded as a single group showing a uniform effect on the pulmonary tissues and producing the same results of disablement and death of those affected." Dr. Badham, also at the Conference, stated that "he was by no means convinced that the silica was the whole story of their disease. He found confirmation of that view in the fact that where they had, as in Broken Hill, 85 percent of silicates, most of them intractable, they found in the lung after death intractable and other silicates. It was therefore reasonable to assume that silicates had a considerable effect on the production of fibrous pneumonoconiosis."

Brief reference will now be made to the clays used in the manufacture of pottery. The "clay body", consisting largely of kaolin (china clay) formed from the decomposition of felspar, contains fibers of sericite. * * *. These readily become freed into the atmosphere from the dried clay.

In discussing the above paper Irvine (153) said that the fact that this very important contribution to the subject had been so long delayed was a

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forcible illustration of the sometimes unfortunate results of the division of science into more or less independent special professional department - the division was necessary but apt to be to some extent harmful, as the mineralogists, chemists, mining engineers, pathologists, and other medical men, in general, know very little about each other's business. He then summarized the history of the silicosis question from this aspect:

> When, 30 years ago, interest was awakened or re-awakened in the problem of "miners' phthisis" by the recognition of its prevalence on the Rand, in Cornwall, in Australia, and elsewhere, it was looked upon in this country as purely an affair of gold mining on the Rand. And when we were told by the mineralogists and the chemists that the Rand banket was composed of 80 to 90 percent of free silica and the remainder of silicates, pyrites, and small quantities of other minerals, we were satisfied with this account, because it was at that time accepted all over the world that free silica was the agent wholly or mainly incriminated. Not only so, but it was also accepted that the gold mines of the Rand were the only significant producers of silicosis in South Africa. I am not aware that any petrologist until now has ever questioned the free-silica hypothesis or has seriously contributed to an exact solution of the undoubted difficulties which that hypothesis was later on found to present. Probably they may say that they were not asked; if so, the more was the pity on both sides. In any case the free-silica tradition held unquestioned sway for many years all the world over.
>
> When Doctor Pitchford and R. Moir in 1916 published their paper on the mineral content of silicotic lungs they were perfectly well aware that both the banket and silicotic lungs contained sericite. But, probably under the influence of the silica tradition, they appear to have underestimated the proportion of sericite in the lungs, and they overlooked the possible pathological importance of its presence.
>
> Then there followed a middle period during which, with a more extensive knowledge of silicosis-producing industries, certain difficulties in the free-silica tradition became increasingly apparent. Why was it that certain rocks which had a high free-silica content did not appear to produce silicosis, while others with a much lower silica content did so? The first answer suggested to that question was that associated in particular with the honored name of Dr. J. S. Haldane, namely, that the apparently innocuous rocks contained other constituents which were in some way antidotal to the action of silica. Then there came further obstinate questionings. "Was silica after all the whole story of the disease?" Was it not "reasonable to assume that silicates had a considerable effect in the production of fibrous pneumonoconiosis?" The Australian delegates to the Silicosis Conference in 1930, in particular (and notably Doctor Badham), voiced this suggestion. The radiographs of cases of silicosis from Broken Hill in Australia could be matched point by point with radiographs of Rand silicosis. Yet the silica content of Broken Hill ore is decidedly low and in parts extremely low. This made one think, but, as the journalists would put it, apparently we did not at the Conference think quite "furiously" enough. Journalists, I notice, always think "furiously."

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> And now with Doctor Jones comes apparently a third period. He has supplied at long last and and for the first time an exact, direct, and extensive petrological attack upon the problem, and his results appear to show that we may have to turn the problem right round in order rightly to understand it. It is not the presence of "antidotal" substances along with silica in the innocuous siliceous rocks, but the presence of fibrous mineral silicates such as sericite and sillimanite in the harmful rocks, which is, on his hypothesis, the solution of the puzzle, while the actual proportion of free silica present is of relatively lesser importance. Apart from the very strong direct evidence which Doctor Jones adduces, a considerable degree of prima facie support for his view is obtained from the fact that asbestos, also a fibrous silicate, is known producer of a pulmonary disease analagous to but not quite identical with silicosis.

Irvine was not sure whether anyone had proved conclusively that a true noninfective silicosis had been produced experimentally by inhalation of pure quartz dust, nor did he know whether sericite could readily be separated mechanically from its admixtures with quartz and other minerals. Mavrogordato (154) said that when he started working on this subject in Doctor Haldane's laboratory he used finely ground pure silica to produce a perfectly good silicosis in animals. He was particularly interested in Jones' hypothesis that the ordinary processes of rock-breaking and handling yielded only a small porportion of quartz particles of phthisis-producing size; this might account for the fact that he (Mavrogordato) produced silicosis in animals with finely powdered quartz artificially prepared. It was not suggested by Jones (155) that sufficient minute particles of quartz could not, under any circumstances whatever, enter the lungs to cause silicosis, although the cases investigated appeared to show conclusively that they had not done so; but it was maintained that the fibrous minerals hastened the process so very considerably that their presence in the exploited rocks and materials was of far greater importance in causing the disease than the presence of quartz.

Mitchell (156) questioned Jones' statement that dust from rocks that contained no sericite had never caused silicosis and quoted from the literature cases in which exposure to silica dust that contained no sericite or only a small amount had caused the disease. One industry, in which the dust contained 96 percent SiO_2 and only 4 percent alumina potash, had an annual mortality of 7.71 per 1,000 from phthisis and pulmonary fibrosis; the material used in this industry, Mitchell said, apparently was of the very type which Jones claimed had not caused a single authenticated case of silicosis. Mitchell also made the following statement regarding the examination of biscuit placers and fettlers in the pottery industry, as reported in the literature:

> As far as I have been able to determine, the fettlers work with a mixture of clays, china clay, felspar, etc., material which is, to a very great extent, made up of the hydrated silicate of aluminium.
>
> Doctor Jones, in fact, states that in china clay fibers of sericite are numerous and that they readily become freed into the atmosphere from dried clay.

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The biscuit placers, on the other hand, work with a very finely ground flint, that is, with material which is almost pure silica (98 percent SiO_2 in an extremely fine crystalline condition).

Doctor Jones has submitted that silicate and not silica is the main cause of silicosis and I find it difficult to reconcile this submission to the fact that silicosis is very prevalent amongst the biscuit placers, who work in an atmosphere containing much less silicate and far more silica than the atmosphere breathed by fettlers.

If silicates and not silica were the main cause of silicosis, then why the apparent immunity of the fettlers from the disease?

I understand that one of the silicotic lungs examined by Doctor Jones was that of a china biscuit placer and I presume that, in that case, as in all others, he found a very high percentage of silicates. A chemical analysis of the air in that process shows a low percentage of alumina and potash and a high percentage of silica. This, together with the fact that the material worked with is almost pure silica, naturally causes one to wonder as to the source of silicates he found in the lung. I have no doubt that Doctor Jones, in a very simple manner, will be able to explain the apparent anomalies to which I have referred.

Flugge-de Smidt (157) emphasized the importance to engineers of Doctor Jones' discoveries as follows:

Doctor Orenstein, in proposing a vote of thanks, did not seem to realize the practical importance of Doctor Jones' discoveries. Except in the matter of the elimination of the unfit, the medical fraternity cannot claim very much credit for the reduction of the incidence of phthisis. It is the mining engineer who, mainly through increased ventilation, has been responsible for the betterment of our conditions and to the mining engineer Doctor Jones' investigations are of the greatest practical importance in the problems of dust determination and dust prevention.

According to Ranson (158), the results of Doctor Jones' investigation on the causation of silicosis have clarified the anomaly of certain ore bodies carrying a high percentage of quartz having no apparent deleterious effect on the worker and a deposit with a similar quartz or silica content readily producing silicosis. He said:

Doctor Jones in his investigation adopted new and original methods, and it has to be admitted that in advancing the theory that sericite crystals or fibers are the principal cause of miners' phthisis or silicosis he has put up a very convincing case. At the same time it is difficult to imagine that such a phenomenon was not generally recognized, when one considers the renowned workers and investigators we are fortunate in having here who have spent many years in thoroughly examining every phase of the subject.

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The presence of silicates in the Rand banket is generally well-known and I believe it is also recognized that the percentage tends to increase steadily from west to east along the reef. It has been the general belief that such dust particles played no part in the development of silicosis and that minute particles of free silica were the primary cause of the disease.

The findings of Doctor Jones may not be generally and immediately accepted as conclusive, but they have opened up additional avenues of research which may lead to finality in determining the principal cause of miners' phthisis on the Rand.

Stokes (159) wondered, as did Flugge-de Smidt, whether Orenstein had been adequate in his appreciation when proposing a vote of thanks to Jones. According to Orenstein, Jones had added one more stone to the structure upon which the efforts against phthisis had been built. Stokes suggested that in addition to giving them that extra stone Jones, first of all, had had to demolish a wood and iron structure of scientific fallacy - the free-silica fallacy - which had been accepted for 40 years.

Truter (160) introduced another point of discussion:

The sericites or free silica are, we believe, the primary cause of silicosis. I have examined miners for many years and have come to the conclusion that besides the sericites and free silica there are also other factors at play that cause the disease of silicosis.

My reason for making this statement is: Why should two men work under the same conditions underground, the one contract silicosis after 2 years and the other not after 14 years? This is very difficult to understand, unless there are also other factors along with sericite and free silica that produce silicosis. One man I examined worked for 29 years underground on the Reef, 27 years of which period he worked on machines (machine work is considered to be most productive of the disease silicosis). This man was old and by no means fit. I would have liked to have been able to recommend him for compensation. I had him X-rayed and re-X-rayed but could not prove that he even had the slightest beginning of silicosis. On the other hand I examined a man who spent 2 years underground, left the mines, was out of the mines for the following 5 years and at the end of that time had a definite silicosis.

Such histories are by no means as rare as imagined.

As I said, this is difficult to understand, unless there are some other factors combined with free silica or sericite which go to assist to establish the disease. Are these factors mechanical, physiological, pathological, or what? For these reasons the scientific bodies should combine and try and solve the question of "prevention of silicosis."

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Jones (152) responded that Irvine, Mavrogordato, Orenstein, Simpson, and Strachan agreed that the great bulk of the dust found in the silicotic lungs of Rand miners consists of minute acicular fibers and asked:

> What are these thousands of mineral fibers that are so conspicuous in the sections of silicotic lungs and in the residues obtained from them, when these are examined under the petrological microscope? * * *. Petrological examination of the fibers in the silicotic lungs of Rand gold miners shows clearly that they are sericite.

With regard to Mitchell's reference to the literature, Jones (152) suggested that references to minerals by medical authorities should always be checked by the examination of such minerals under the petrological microscope, as otherwise mistakes would be perpetuated.

In the discussion of a similar paper presented by Jones before the Institution of Mining and Metallurgy in London in January 1934 Haldane (115) dissented most emphatically from the conclusions drawn by Jones. Haldane pointed out that what seemed to him to constitute perfectly clear evidence incriminating uncombined silica was not the nature of the dust found in the lungs at death, but the history of prolonged exposure to dust containing a high proportion of uncombined or free silica. He found nothing to indicate that either the presence or absence of sericite had anything especially to do with the silicosis produced by quartz, while the evidence incriminating dust with a high percentage of quartz was overwhelming. Although he had once attributed the harmlessness of diluted free silica to a special quality of the diluent dust, Haldane said he had been converted by the experiments of Gye and Kettle - which indicated that the dissolved silica had positive detrimental effects - to the opinion that it was the action of the silica and not the absence of positive action of other dust that was important. He explained the presence of sericite in the silicotic lung as due to the fact that free silica dissolved gradually in an alkaline liquid, while natural silicates were much less soluble. The very small particles of free silica would therefore disappear more quickly in the living lungs, leaving silicates and only relatively large particles of free silica, as Jones had found. The free silica if in sufficient concentration and in a fine enough state of division in the phagocytic cells went into solution in their slightly alkaline medium and in so doing paralyzed their activity in both removing dust and handling tubercle bacilli, but if sufficiently diluted with other dust of any kind it would do no harm. At death nearly all the finely divided silica would have dissolved, leaving a residue of natural silicates and only relatively large particles of free silica. Haldane claimed that the smaller particles which had disappeared had done the real damage, not the large particles. Kettle (115) admitted that sericite might be responsible for a great deal of industrial silicosis, but he was not very much impressed with Jones' negative evidence that silicosis was not contracted where sericite was not present. It seemed to him to be going much too far to suggest that silica itself was incapable of producing the disease; conditions in the mines or in the various factories might interfere with the entrance of dust into the lungs, and the anomalous distribution of silicosis might depend on some such factor. He said the question of the solubility of silica was of great importance; there could be

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no doubt that a too readily soluble silica was just as incapable of producing lesions of silicosis as an absolutely insoluble silica. It had been shown that these lesions could be produced by the intravenous inoculation of crystalline silica; also in his laboratory the intravenous inoculation of amorphous silica had proved incapable of producing these lesions; such evidence indicated the complexity of the whole process. In conclusion, he stated that in his opinion Jones had presented a very strong case in support of his view that sericite was responsible for a great deal of industrial pneumoconiosis.

According to Industrial Medicine (161), a number of opportunities to examine samples of dust for sericite fibers have been presented in the United States. When examined petrographically samples of material collected where a great deal of drilling was being done through siliceous rock did not show an appreciable amount of sericite material, although it was definitely known that silicosis occurred by exposure to this type of dust. A recent report issued by the Commonwealth of Massachusetts (101) relative to the findings of the Special Industrial Disease Commission also mentioned the examination of samples of different types of granite and foundry dusts. In certain petrographic examinations sericite was not found, in others it was found in very small quantities, and in additional samples the amount was appreciable. Although no general conclusion was reached the petrographers believed that in industry sericite could be avoided more easily than quartz.

The October 12, 1934, issue of the Colliery Guardian (162) quotes Irvine to the effect that "the apparent negative instances from the Mysore (Indian) gold field and the Lonely mine in Rhodesia are neither of them convincing, because neither so far has been adequately investigated." At one time it was said that there was no disabling silicosis in Cripple Creek in the United States; however, according to Russell (163), silicosis undoubtedly occurred there, but the miners who developed the disease left as soon as the altitude began to trouble them, and their deaths were recorded elsewhere.

Early in 1934 the Mysore Government appointed a special committee, consisting of the chief medical officer of the Mining Board Kolar Gold Fields, the local medical officer of the Mysore Government, and the physician of the Krishnarajendra Hospital, Mysore, to investigate the prevalence of silicosis among the miners on the Kolar gold-field area (164). The committee conducted a preliminary investigation and unanimously concluded that silicosis does occur among the underground workers but that the incidence of the disease in the field is much smaller and a much longer time is required to develop signs and symptoms than in South Africa. This difference evidently is due to the fact that Kolar rock contains only 5 to 20 percent of free silica, whereas the South African samples contain 43 to 98 percent. Under the circumstances Irvine, of South Africa (164), has felt it necessary to contradict the statement that "in the Kolar gold field, India, where the rock contains a large amount of quartz and sericite is absent, silicosis has hitherto inexplicably been unknown."

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Properties of sericite.- According to Jones (152), sericite, sometimes called "secondary white mica", is a hydrous silicate of aluminium and potassium containing (analysis of specially selected pure material) 46.53 percent SiO_2, 37.46 percent Al_2O_3, 0.80 percent Fe_2O_3, trace of CaO, 1.16 percent MgO, 6.38 percent K_2O, 0.64 percent Na_2O, 6.06 percent water above 110° C., and 0.30 percent water below 110° C. He said that sericite is most common in rocks that contain a high percentage of free silica in the form of quartz but is not present in all rocks that contain quartz; that the dust from rocks that contain abundant sericite as aggregates of acicular fibers has been proved to cause silicosis; and that the dust from rocks that contain no sericite or only occasional crystals of it but which contain a very high percentage of quartz - as high or higher than the rocks that had proved dangerous - apparently has not caused a single authenticated case of silicosis.

Carbon dioxide theory.- An article in the Canadian Mining Journal for September 1934 called attention to the interesting theories and facts brought out in the discussion of Doctor Jones' paper on sericite as a cause of silicosis. Edge's (165) theory is based on the liquid inclusions in quartz and other minerals, a fact known to petrologists for many years but one that has received little attention. Edge examined carefully specimens of quartz from mining districts where silicosis is prevalent and found that the quartz of these regions carries liquid inclusions, while that of areas free from silicosis carries very little; he therefore suggests that this fact may have some bearing upon the disease. The Journal discusses the matter as follows:

> The remarks of Mr. Edge on milky quartz from the Hollinger are of more than ordinary interest. He points out that, as expected, the microscope revealed that the whiteness of the quartz was due to the reflection of light from immense numbers of minute cavities, each containing liquid and a gas bubble. In the Hollinger quartz he found that the number of the visible cavities per cubic millimetre was of the order of 1,000,000, being seldom less than 200,000, and rarely more than 3,000,000.
>
> He goes on to say "many of the cavities were found to contain two immiscible liquids as well as a gas bubble, the latter incidentally being kept in a perpetual state of agitation by the Brownian movement of the gas molecules within it. Of the two liquids, one was easily identified as liquid carbon dioxide by means of its critical temperature (31° C.). The other liquid appeared to be water or an aqueous solution of some kind."
>
> Naturally, with the presence of liquid carbon dioxide established, it was easy for the investigator to deduce the pressure existing in these cavities for any particular temperature. Thus, if a piece of this quartz was placed in the mouth for a few moments its temperature would be raised to that of the body (37° C.), which is 6° above the critical temperature of CO_2.
>
> It follow, therefore, that, with the quartz subject to body temperature, all the contained CO_2 would be in the gas phase, and by referring to tables of physical data, it immediately becomes obvious that the

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pressure within the cavities is in the vicinity of 84 atmospheres, which is more than half a ton to the square inch. Mr. Edge points out that "furthermore, if the pressure were suddenly released, say by the solution and ultimate bursting of the walls of a cavity, the compressed CO_2 would expand almost instantaneously to about 400 times the volume which it occupied within the cavity. In fact, some of the quartz specimens examined contained between 3 and 4 times their own volume of CO_2 if the latter were released to conditions of normal temperature and pressure."

Mr. Edge found similar conditions in the quartz of the Rand. As he points out, quartz particles taken into the human lung can contain a great number of these cavities, and there is some interesting food for thought in speculating upon exactly what happens if these particles are disintegrated and discharge their gases under pressure into the surrounding tissue. Mr. Edge does not advance these possibilities very far; but his work on the liquid inclusion of milky quartz is very interesting and may present another field of investigation.

Irwin (166) reports the following results of investigations carried out at the Banting Institute (Toronto, Canada):

Since little or no silicosis was observed in workers on the crushers of gold and other mines, it was subsequently suspected that the gases in the mine atmosphere might prove to be an important factor accelerating silicosis, and experiments were carried out in which such gases as sulphur dioxide and nitrous oxide were used in minute proportions. Later, when Dr. W. R. Jones suggested that sericite and not quartz was responsible for miners' fibrosis, it was decided that the workers at the Banting Institute should perform their experiments in three groups. The effects were observed on animals in: (1) An atmosphere containing mine gases alone; (2) an atmosphere containing mine gases and quartz dust; (3) an atmosphere containing mine gases and sericite dust. From these experiments it seemed doubtful whether real silicosis was initiated, since no definite lesions were noted in the lungs.

The following conclusions had been drawn during the investigations: (1) That all people aggregated a cumulative amount of silica in certain organs, from birth to old age, and that if a man lived to, say, 200, he would probably resemble a silicotic case; (2) that silica was fairly soluble in the body and that the organs of excretion threw off a certain amount; (3) that the gases used in their animal experiments damaged the organs of excretion, and thus a higher amount of silica was retained by the animal; (4) that the mineral particles in the lung revealed by the microscope played little or no part in the acceleration of silicosis, but that the fibrosis was caused by some form of "easily soluble silica", probably introduced in extremely minute form.

Nature of silica dust.- Research in the field of dust inhalation appears to have demonstrated that, in general, the degree of health hazard associated with the inhalation of any dust, all other factors remaining constant, depends upon the mineral composition of the dust. Knopf (167) states that the harmfulness of a quartz-containing dust usually is in direct proportion to its

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quartz content; therefore, in an attempt to evaluate the harmfulness of a dust it is of great importance to ascertain its exact mineral composition.

A long-established convention has led to the reporting of chemical analyses of rocks and minerals in terms of certain chemical compounds (usually oxides) rather than in terms of chemical elements (167). During analysis the silicon is isolated in the form of silica; consequently the chemical analysis of an average granite, for example, is reported as containing 70 percent of silica. About 30 percent (roughly one third) of the entire granite is quartz, whereas the other two thirds of the granite comprises chiefly complex mineral salts of silicon-bearing acids; such minerals are known as silicates. The remainder of the silica reported in the chemical analysis of granite (40 percent) is locked up in these silicate minerals, chiefly feldspar and mica.

This arbitrary convention of reporting rock and mineral analyses in terms of oxides has necessitated the use of the expressions "free silica" and "combined silica" to distinguish the silica that makes up quartz (or the few other minerals that are composed of silica alone) from the silica combined with other elements in the various silicate minerals (167). In the granite cited the 70 percent total silica is the sum of 30 percent free silica and 40 percent combined silica.

According to the Industrial Health Section of the Metropolitan Life Insurance Co. (168), although obviously dust containing 90 percent silica is more harmful than dust containing 60 percent, it is not known whether the relative harmfulness is one of strict arithmetical proportion.

The argument whether the cause of the lung condition called silicosis is due to free silica or to sericite has not been settled. With white mica dust Policard (169) produced experimentally pathological lung changes identical with those produced under the same experimental conditions by inhalation of various siliceous rock dusts, such as sandstone. He assumes that in the latter case the noxious constituents are minerals of the mica family, such as sericite, and not the classically accepted free silica. According to this author,

> The results obtained favor Jones' sericite theory as to the causation of pulmonary silicosis and show how fragile and uncertain is the pathogenic basis for the current conception of pulmonary silicosis.

Gollis (170) made the following comment in his abstract of Policard's paper:

> The observations ceased 30 days after dusting, which Kettle has shown to be far too early to determine the "activity" of a dust. Further, the special characteristic of silicosis is its tendency to encourage the growth of tubercle bacilli; it is this which constitutes its noxious nature, not some microscopic reaction. No attention is paid to this matter.

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On the other hand, LeClerk (171) reports that of 350 selected underground coal-mine workers carefully examined by physical, X-ray, and clinical laboratory methods 271 were negative, 20 showed discrete benign fibrosis not associated with occupation, 15 had lesions of noninfective pulmonary fibrosis undoubtedly due to anthracosilicosis but with no associated incapacitation, 18 had clinical and radiographical signs of silicosis with slight incapacitation, and 26 had traces of infective pulmonary sclerosis. In this group 13 were definitely silicotic; 8 had definite signs or were strongly suspected of having tuberculosis, and 5 had silicosis with tuberculosis. These cases developed among miners working in a coal-bearing stratum paralleled by strata of sandstone and schist, both of which contain free silica. The fibrous silicate, sericite, does not occur in this region. Of 177 samples of mine dust examined 93 showed crystalline silica in varying amounts (10 to 60 percent).

In his report of a study of silicosis in the granite and foundry industries of Massachusetts Pope (172) states that petrographic analysis showed sericite in significant amounts in the granite from only one city studied - Fitchburg - where the incidence of silicosis was low. In the granite from Milford, where the incidence of silicosis was more than three times as great, barely a trace of sericite was found.

Particle size of dangerous dust.- The significant part played by the size of dust particles is indicated by the fact that although in South Africa visible dust has been very largely removed from the air breathed by the miners silicosis is still produced. Pirow (173) is not convinced that the Rand standard of 300 particles per cubic centimeter is safe. Mavrogordato (174) emphasizes that all visible dust can be easily removed, leaving the dangerous dust; therefore size frequency is of great importance. Naturally the more concentrated the quantity of dust and fume in suspension in the atmosphere the greater the danger to which the workman is exposed, and unquestionably the smaller the particles the greater the likelihood of their entrance into the interstices. The size of particles in prolonged suspension in the air is more likely to be under 5 microns than over; probably the most dangerous dust is that ranging from 2 microns to 0.5 micron or smaller because these impalpable particles readily remain in suspension in the air for long periods of time. The size of fume particles ranges from 1 to 0.2 micron in diameter. In other words, it is thought that the smaller the particles the greater the danger, although there may be a lower limiting size as well as a higher one; unless especially warned, employers and workmen are prone to regard impalpable nonvisible dust as altogether harmless. Dust particles under 5 microns in size readily pass through the mouth and nose, traverse the bronchial passages, and lodge in the alveolar tissue, from which remote parts of the lung structure they usually cannot be dislodged by hawking or coughing. The size of the dangerous dust (supposedly 1 to 5 microns) is roughly that of the tubercle bacillus. Such particles are like smoke or vapor; they cannot be washed down by spray since they recoil from drops of moisture, nor can they be conceived as exerting an abrasive action when moving gently within the lungs. Since similarly fine particles of other dusts when inhaled are not followed by the pathological changes characteristic of silicosis the conclusion (and this is now held by many, probably most,

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authorities on the subject) is that silica dust exerts a chemical rather than a physical action upon living tissues. Badham, Rayner, and Broose (175) suggested that if every individual particle is equally dangerous in initiating fibrosis then the 1-micron particle is the worst because it is in the majority; if fibrosis results from chemical action depending on solubility of dust particles then the 2-micron particles are the worst because this size exposes the largest surface; but if the quantity of dust is the most important factor then the 3-micron particle is the worst since this size contributes the most weight. If number, surface, and weight are factors then sizes of 1 to 3 microns are the most pernicious (these authorities apparently are at least somewhat doubtful as to the underlying cause of dust harmfulness). Greenburg (176) considers a knowledge of the weight of dust of much value, but because it is virtually impossible to separate the particles less than 10 microns in size from those over 10 microns to obtain the weight of the injurious particles (those capable of gaining access to the lung tissue) and also because one large particle may weigh many hundreds of times more than a smaller one, the weight of a given sample of dust must be used only as an additional guide in the interpretation of results, and then with some degree of caution.

Quantity of dust required to produce silicosis.- According to Loriga (74), the quantity of dust that will provoke silicosis cannot be given precisely, since it is not the absolute quantity or quality that matters but the relative quantity. One person might resist a proportion of 100 particles per cubic centimeter, while another would react unfavorably to 50 particles; there is also the whole question of the rate of inhalation.

According to Ballantyne (108), in Great Britain the criterion of safety suggested, rather than expressed, in the Workmen's Compensation Schemes goes no farther than the composition of the mineral substance itself. The composition of the dusty atmosphere - that is, the concentration of the SiO_2 therein - is not mentioned; the Refractories Industries Scheme does not apply if the mineral contains less than 80 percent total silica. In the sandstone industry the Scheme ceases to apply if the sandstone is shown to contain less than 50 percent. In the United States (108) it is customary to gage the risk by the number of particles of free silica per cubic foot of air, irrespective of the other constituents of the dust. In South Africa (111) the total number of mineral particles per cubic foot is taken as the basis. Certain standards, chosen more or less empirically from a study of particular industries, have been adopted on these lines. Ballantyne (108) thinks that international agreement on methods of estimating the number of dust particles in the air and of interpreting the "counts" obtained is much to be desired.

Badham (177) states that if the average exposure on the Rand is about 1 mg per cubic meter the prospects of attacking the disease by reducing the amount of dust inhaled seem rather hopeless.

In South Africa, where the dust is said to contain more than 85 percent free silica as quartz, a tentative standard of 300 particles per cubic centimeter of air (8.5 million particles per cubic foot) has been set (178) as the upper limit of dustiness to be regarded as allowable.

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Investigation in certain plants of the granite-cutting industry in the United States (178) revealed a content of 31 to 38 percent free silica in the form of quartz. In a study by the Public Health Service (178) the workers were divided into four groups, depending upon the average exposure in terms of amount of dust in the air, with the following results:

> In group A, which included hand-pneumatic tool operators and in which the exposure averaged about 59 million particles per cubic foot of air, it was found that practically 100 percent developed an established silicosis within 10 years from the time of beginning employment. Also, in this group the highest rate was found for cases diagnosed on physical examination as having active tuberculosis. * * *.
>
> In group B were included those workers other than hand-pneumatic tool operators who were also exposed to more than the average plant dustiness. Taking the group as a whole, the average dust concentration was nearly 45 million particles per cubic foot of air. This group showed the same reflection of a dust hazard as group A.
>
> In group C, consisting of those occupational groups exposed to the average plant dustiness (about 20 million particles per cubic foot of air), silicosis developed much more slowly than in the groups just discussed and there appeared to be very little excess in the rate for tuberculosis, with no tendency for an increase according to length of service. Analysis of occupational mortality over a period of 25 years, however, indicated that some of the occupations in this group may have been exposed to a real dust hazard.
>
> Group D was made up of those occupations in which the dustiness was less than that of the average plant atmosphere. The average exposure for the group was less than 10 million particles per cubic feet of air. Although a certain amount of silicosis was found even in this group, there was no indication of serious results, even when the workers had been employed for many years.
>
> From the results of this study it was found practicable to suggest a tentative standard for the upper limit of allowable dustiness between 10 and 20 million particles per cubic foot of air for workers exposed to dust resulting from granite cutting. The same limit would presumably be applicable in the case of other dusts with the same physical characteristics, particularly with a quartz content of about 35 percent.

The Industrial Commission of Wisconsin reports (179) as follows regarding the amount of dust to be allowed in the air breathed by workers:

> The maximum silica-dust concentration considered permissible in the air breathed by a workman at any point in the normal breathing zone has not been definitely established. The commission, its advisory committee, employers and scientists have agreed on a tentative figure of 15 million countable dust particles under 10 microns in longest dimension with free-silica content of 35 percent in a cubic foot of air as

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determined by United States Public Health Service technic. Variations in free-silica content will make proportional inverse changes in this standard. In the case of practically pure silica the permissible dust count would be 5,250,000 countable particles. By countable particles is meant those particles within the range of size from 2 to 10 microns in the longest dimension. Dust particles larger than 10 microns in the longest dimension do not ordinarily reach parts of the body where they can produce injury.

From a study made in a bituminous-coal mine the United States Public Health Service (180) found that the incidence rate of respiratory attacks in those exposed to heavy concentrations of dust (105 million particles per cubic foot of air) was 79 percent above that in the group exposed to relatively little dust (3 million particles per cubic foot of air) and 83 percent higher if based on the men employed throughout the period of the study. The excess lies in minor, upper respiratory disease.

Tillson (181) calls attention to the factors affecting the transportation of dusts by the wind as vital to the problem; they are size, shape, and specific gravity of the dust particles and the velocity, density, viscosity, adsorption, wetting power, humidity, temperature, and pressure of the transporting fluid. Various ratios, such as the maximum projected area of surface per units of volume and mass and the total surface area per units of volume and mass, are important derivatives of the particle factors. A thin flake or a needle form (acicular shape) will have a slower settling rate from a horizontal stream than a spherical form of the same volume and mass.

According to Tillson (181), the silica dust found in the lungs has a maximum dimension ranging from less than 0.5 micron to a maximum of about 10 microns (or about 0.0004 inch). Some experts hold that dust less than 0.5 micron in size remains suspended in the expired air and so does not lodge in the lungs, but Tillson doubts whether the evidence is strong enough to warrant such a conclusion. He thinks that too little attention has been given to the form factor of the dust particles in the study and tabulations of dust counts; some observers believe that dusts in the size range 0.5 to 3.5 microns are the most dangerous because of two factors - percentage of surface exposed and percent of volume, respectively, in each intermediate size compared with the total surface of total volume of all sizes from 0.5 to 10 microns when their frequency ratio in the whole amount of such dust is considered. Many persons believe that dust over 5 microns in size is not particularly dangerous.

Tillson says (181) that it is an oversight to consider the dust particles recovered from the lungs by post mortem as evidence of the size and nature of the particles that are most dangerous, because silica dissolved in the slightly alkaline fluids of the body is thought to be responsible for abnormal conditions of the cell structure of the lungs; therefore, the dust that has produced the disease probably has been partly or wholly dissolved and cannot be recovered. Moir (182), of South Africa, found that 13 percent of 126 dust particles from 2 specimens of a silicotic lung were less than 0.5 micron, 36 percent less than 1 micron, and 60 percent 1 to 3 microns, so that the median

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size was 1.3 microns. Bloomfield (183) studied 11 different kinds of aerial industrial dusts and found only 3 percent less than 0.5 micron, 21 percent less than 1 micron, 71 percent 1 to 3 microns, and the remainder less than 5 microns. Badham (184), of New South Wales, found that 67 percent of the dust particles smaller than 8 microns examined by him were below 1.5 microns in maximum dimension and that only 1 in every 3,000 was 8 to 10 microns or greater. The authorities at Broken Hill, New South Wales, found that for every particle, in a count of 3,500 particles in lung sections, having a diameter greater than 7.5 microns at least 100,000 particles of a smaller diameter were present; but McCrae (185), of South Africa, found that 70 percent of the quartz particles in the ash of silicotic lungs was less than 1 micron in size. Premised on the number of particles of silica dust per cubic centimeter of air (specific gravity of silica, 2.64), Badham (184) has computed that the respective amounts, depending on shape of particle, will add 1 mg of weight to 1 cubic meter of air: Tetrahedral particles (triangular pyramids), 400 per milligram; spherical particles, 90 per milligram; and cubical particles, 50 per milligram. At an average figure of size-frequency ratio of 3 to 1 he assumes 100 particles per milligram, of which 87 percent by weight are smaller than 5.5 microns. He states that the size-frequency ratio will vary with the time allowed for settling before the sample is taken. In South Africa investigators found that 20 minutes were required for 5-micron particles to settle 6 feet in quiet air and that 8 hours were required for a 1-micron particle to settle the same distance. Jones (186) noted that the granular silica particles settled more rapidly than the smaller acicular sericite particles, so that the percentage of silica dust in the air after blasting was almost invariably lower than in rock borings, noticeably so when samples were taken 3 hours after blasting. He also calls attention to the fact that a 10- by 3- by 5-micron quartz particle taken from a lung has a volume equal to 800 sericite fibers 2 microns by 0.5 micron wide and deep and that the quartz grain has 1,630 times as much silica as the sericite fibers. He does not suggest that no quartz enters the alveoli of the lungs but that he has found scores of sericite fibers there for every grain of quartz.

Jones (186) also states that he extracted 10 grams of dust from the lungs of a man who died from silicosis after 14 years' exposure. Therefore, if the unknown amount of dust which the lungs ejected or dissolved is ignored, the accumulation amounted to 0.0024 gram (240 million particles) per day. He assumes that less than 1/400 gram (250 million particles) per day produces fatal silicosis and states that he has known of other lungs in which the dust proved fatal with only 1/1200 gram (83,300,000 particles) per day. In the former case Tillson (181) assumes from Badham's figures that there were only 1 million million particles in the lungs. The United States Public Health Service has recommended a dust content below 10,000,000 particles per cubic foot of air in granitework where the quartz content of the rock is 35 percent and affirms that 6,000,000 particles per cubic foot of air is the acceptable limit where sand-blasting is done with quartz sand (90 percent or greater content). If the amount of lung ventilation during violent exercise is accepted as 42 to 43 liters per minute according to Tillson (181) about 1.5 cubic feet of air per minute are apparently inspired, therefore the concentration of dust noted above would supply more silica dust in 3 to 3.25 years than has been found as the lethal content left in the lungs. Some writers

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claim, however, that only 50 percent of the inhaled dust remains trapped in the lungs and nasal or respiratory passages, the remainder being exhaled. If the air in the streets of lower Manhattan, New York City, the dust count of which is 3.2 million per cubic foot of air, were entirely siliceous, according to Tillson's calculation about 4 years' exposure might supply the 10 grams cited by Jones, and on the basis of 50 percent elimination 8 years would provide a lethal dose. As cited by Bloomfield (183), dust counts for different occupations of the granite-quarrying and granite-finishing industry ranged from 17 to 144 million particles per cubic foot with a quartz content of 35 percent; in quartz-grinding plants the counts ranged from 55 to 173 million particles per cubic foot with a 99-percent quartz content. Death, then, would be expected after exposure for 54 days. Evidently the human system has more effective ways of disposing of such dust, considerable time is necessary to produce the fatal toxic and pathological changes, or possibly (as Jones suggests) the free silica is not the important dust hazard, but some other mineral present in minute percentages is chiefly injurious.

Watkins-Pitchford (187) has stated that experimental observations on animals show that if exposure to silica dust is intense enough no individual will escape development of nodular pulmonary fibrosis. If the quantity of dust inhaled by miners has been relatively small it may be surmised that the processes whereby the particles are removed from the lungs generally are active enough to prevent that degree of accumulation of particles prerequisite to the development of the ordinary form of silicosis. However, he calls attention to the fact that despite the nondevelopment of silicosis in some of those exposed to dust for a long period it appears that many of them nevertheless are faced with the liability to such development. As an example, he states that several of the long-service miners who took part in the World War and who were nonsilicotic when they left their work had developed the disease when they returned. He considers that this state of liability depends upon the continued retention in the lung tissues of the requisite number of silica particles; it ceases when a certain proportion of them have escaped in the expectoration, have been removed by other channels, or have dissolved finally. The agency which converts the liability into a manifestation of the disease in any particular case is usually a tuberculous infection. The state of the individual thus liable to develop the disease without inhaling any more silica dust is conveniently referred to as latent silicosis.

Length of dust exposure required to produce silicosis.- A significant point mentioned in a medical report by Sutherland and Bryson (188) on the incidence of silicosis in the pottery industry, published in 1926, was the frequency with which fibrosis of the lungs was diagnosed by medical examination at a period of employment earlier than that at which silicosis had been found by radiological examination in the same occupational groups. The report states that possibly fibrosis of the lungs, as found clinically, develops in a shorter time or requires a lower concentration of dust than silicosis discernible radiologically; therefore, in occupations where both conditions are found fibrosis of the lungs commonly precedes silicosis. The cases of silicosis in the pottery industry, grouped in the report according to years of employment, were:

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Years	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	Over 40
Cases	1	2	8	7	14	15	15	8	17

According to this table, most of the cases in the pottery industry develop after 20 years of employment in the industry. The authors consider it significant that in the occupations where the incidence of silicosis is high the disease becomes evident at an early stage in the occupational history (188).

The period of exposure required to produce silicosis depends primarily on the individual, according to Moore (189). In the Bendigo mines the silica content of the dust is over 90 percent; on the west coast of Tasmania, about 80 percent; and in Kalgoorlie, a little above 60 percent. Moore (189) states that the Bendigo statistics are not very trustworthy, as the miners are loth to be examined, but the average period required to produce silicosis seems to be about 10 years; in Kalgoorlie it is nearer 16 years. He concludes that silicosis seems to depend pretty accurately on the silica average in the country rock.

Böhme (190) cites German experience to show that sand-blasters and sand-grinders have well-developed silicosis sometimes after 3 years' exposure; generally it develops after about 10 years. Koelsch (191) observed that 2 cases of severe silicosis developed after 2.5 years of employment on sand-blasting; the workers were 25 and 30 years old, respectively.

According to Cunningham (192), the exposure necessary to produce ante-primary silicosis in Ontario gold mines is 9 to 10 years. The percentage of free silica is about 30 to 35. In England the apparent exposure to silica dust necessary to produce silicosis has been short; Middleton (193) mentions a case of fatal tuberculosis with evidence that it had been produced by silicosis after 2.5 years of exposure.

More investigative work on silicosis has been done in South Africa than in any other country; the following summary of experience in that country on this phase of the subject is therefore interesting (194):

> In previous reports one has had occasion to emphasize the fact that the data regarding the mean duration of service of new silicotics obviously apply only to those miners who do actually contract the disease. They cannot be taken as a measure of the "average effective life of a miner" in the sense that all working miners will on the average become silicotic after some 14 years of underground work, since they leave out of account the service of the remaining miners who have not contracted the disease, and some of whom may never do so.
>
> On the rates of incidence of the compensable diseases which obtained in 1918 to 1920, 50 percent of the original

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body would have become affected by one or other of these diseases by the 13th year of work; on the rates of 1920 to 1923 the corresponding figure would have been the 17th year; on those of 1928 to 1929 the 20th year; while, from the trend of the figures calculated on the incidence rates obtaining in 1931 to 1932, it can be concluded that a corresponding position would not be reached now until between the 25th and 26th years of underground work. This method of analysis affords a concrete illustration of the progressive potential advantage conferred by the progressive fall in the rates of liability to contract silicosis to which reference has repeatedly been made.

The effect of long exposure to granite dust is shown in the history of 8 cases cited by McFarland (195). In 3 cases of simple silicosis the ages were 34, 39, and 42, while the duration of exposure was 14 years in the first case and 23 in the other 2. In 5 cases of silicosis with tuberculosis the ages were 50, 53, 57, 59, and 63, and the years of exposure 35, 42, 34, 38, and 50, respectively.

In a study of sandstone-quarry workers Haymurst and his co-workers (196) found that the stage of silicosis varied in proportion to the years of exposure except that silicosis plus tuberculosis manifested itself as early as beginning silicosis, that is, after about 15 years' exposure; they found that few men suffered from silicosis under 25 years of age but that at 34 there were as many silicotics as nonsilicotics and again after 44 years of age there were sometimes more silicotics than nonsilicotics.

In an investigation of the granite industry the United States Public Health Service (99) found that in the group of workers exposed to the heaviest dust the first case of silicosis appeared after approximately 2 years and by 4 years all in this group seemed to have developed at least an early case of silicosis. In the same group the first case of more developed silicosis appeared after 5 years of service, and by 9 years approximately 90 percent had advanced to this stage. In the group with an average exposure of less than 10 million particles per cubic foot of air 2 cases of early silicosis had developed after 10 years' exposure and 1 case of moderate silicosis after 6 years.

In a similar study of the cement industry the Public Health Service (103) found that the earliest case of pneumoconiosis appeared after 3 years' exposure to cement. Of 53 men selected for examination 37 had worked in the industry more than 3 years. Of the 37, 15 showed evidence of pneumoconiosis, and 3 of these also had tuberculosis; of 22 who showed no indication of pneumoconiosis 8 gave evidence of arrested tuberculosis, 4 showed no evidence of either pneumoconiosis or tuberculosis, and 10 were considered doubtful.

Chapman (197) reported three cases of acute silicosis, among the first cases in American industry, in which the appearance of respiratory symptoms after 8, 21, and 29 months of exposure to an alkaline dust of high silica content marked a more rapid and severe silicosis than usual. He states that the rapidity of the process, in contrast to the usual chronic form, probably was due to the accelerated formation of silica hydrosol in the presence of an alkaline soap dust. MacDonald (198) described the rapidly fatal cases of 2

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young girls who had been employed 2.75 and 4.25 years packing a silica soap powder. According to Chapman, Russell (199) saw the disease fully developed in a lens grinder who inhaled a pure quartz spray for 8 months.

In describing four cases of silicosis or silicosis and tuberculosis which developed many years after relatively short exposures Britton and Read (200) stated that cases of this kind suggest the necessity of revising the conception of the length of exposure necessary to produce the disease and emphasize that once a man has developed symptoms while still engaged in the dusty occupation stopping the work does not prevent the gradual, steady progression of the pathologic changes. The cases described developed symptoms of silicosis 23 years after an exposure of 4 months, 10 years after an exposure of 2 years, 14 years after an exposure of 4 years, and 10 years after an exposure of 10 years. The following table taken from the Colliery Guardian (201) gives the number of deaths from silicosis and silicosis with tuberculosis, by industry, average age at death, and duration of employment reported for 1932 to the British Factory Inspection Service:

Industry	Number of deaths	Average age at death	Duration of employment, years		
			Longest	Shortest	Average
Pottery:					
Silicosis	72	55.6	57.0	10.0	39.8
Silicosis with tuberculosis	75	55.2	67.0	13.0	37.9
Sandstone:					
Silicosis	21	57.3	57.0	20.0	40.4
Silicosis with tuberculosis	39	52.3	53.0	16.0	34.8
Grinding of metals:					
Silicosis	4	47.3	45.0	18.0	30.8
Silicosis with tuberculosis	26	51.1	48.0	2.8	30.2
Sand-blasting:					
Silicosis	7	40.7	13.0	4.5	10.5
Silicosis with tuberculosis	16	44.2	20.0	2.5	8.5
Scouring-powder manufacture:					
Silicosis	3	37.0	11.0	5.25	7.8
Silicosis with tuberculosis	2	33.5	10.75	2.0	6.4
Miscellaneous:					
Silicosis	7	55.3	45.0	2.8	20.4
Silicosis with tuberculosis	9	50.9	34.0	11.0	24.0

The diagnosis of all these cases was verified by post-mortem examination.

Kilgore (202) shows the course of six cases of pneumoconiosis developed after comparatively short exposures to pulverized quartz used in a polishing powder:

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Case	Age, years	Dust exposure, months	Onset after exposure, months	Life after exposure, months
1	70	16 (not grinding quartz)	(?)	84
2	50	27	(?)	23
3	36	14	14	Still living
4	39	14	24	50
5	31	10	9	14
6	31	12	11	21

In a study (90) of the effects of exposure to dust in coal mining the Public Health Service found an apparent relation between the occurrence of generalized fibrosis and length of time the workers had been employed in the industry. The percentage rises from 4.8 in the group with less than 5 years' service to 69 in the group with more than 15 years' service; even if attention is confined to workers under 45 years of age, the percentage in the group with more than 15 years' service is 66.7.

Pancoast and Pendergrass (22) found that the longest period of occupation in a sand-pulverizing plant was 2.5 years at intervals , and the shortest was said to have been only 35 days during a period of a little over 1 year before symptoms of lung affection appeared.

Quaintance and Morris (203) examined 58 pottery workers in an industrial plant manufacturing bathroom ware, using a silica content of approximately 25 percent. After an average exposure of 16 years 8.6 percent of these workers had advanced fibrosis; 38 percent had second-stage or moderate fibrosis, and 63.5 percent had only slight fibrosis.

Data collected by the United States Bureau of Mines (89) at Picher, Okla., show that first-stage silicotics had worked underground 2 to 30 years, an average of 12.99 years for all men, irrespective of occupation; for facemen, 12.34 years; and for men exposed to large amounts of dust, such as drillers, shovelers, and their helpers, 9.6 years. Second-stage silicotics had worked underground 2 to 36 years, an average of 15.8 years for all men, irrespective of occupation; for facemen only, 13.3 years; and for drillers, shovelers, and their helpers, 12.8 years. Third-stage silicotics had worked underground 3 to 40 years, an average of 18 years for all occupations; for facemen only, 16.1 years; and for shovelers, drillers, and their helpers, 15.5 years. The average number of years worked before the various stages of silicosis developed is shown in the following table (92):

	Years
First-stage silicosis	11.9
Second-stage silicosis	14.3
Third-stage silicosis	17.1
First-stage silicosis plus tuberculosis	19.4
Second-stage silicosis plus tuberculosis	18.0

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	Years
Third-stage silicosis plus tuberculosis (only 2 cases)..	11.5
Early tuberculosis.....	8.7
Moderately advanced tuberculosis.....	21.2
Advanced tuberculosis (only 1 case).....	30.0

Examination of ex-coal miners failed to reveal any benefit from previous exposure to coal dust. Of the 599 ex-coal miners who had worked in coal mines for periods ranging from a few weeks to 52 years (average, 12 years) 167 had silicosis in 1 of the 3 stages. The periods that these coal miners worked in zinc and lead mines averaged 7.7 years for first-stage silicotics, 9.0 years for second-stage silicotics, and 14.9 years for third-stage silicotics

Lochtkemper and Teleky (66) found that silicosis developed after 2 years' work in a polishing-powder factory and in sand-blasting with the free blast, both occupations showing the highest number of dust particles; in automatic sand-blasting rooms with only 160 dust particles per cubic centimeter silicosis did not develop until after 4 or 5 years' exposure. An early case of silicosis developed in the crushing mills after 3 months' work, stage II after 1.75 years, and stage III after 2.75 years. Stage III silicosis developed after 6 and 15 years' exposure in cementworks, where the greatest number of particles were quartz sand; when the quartz dust was mixed with clay dust stage III silicosis was reached sooner.

Droessen (204), in his study of the effects of silicate dusts, found pulmonary fibrosis or pneumoconiosis in all 6 workers who had been exposed for 6 years or more to 1,440 million particles per cubic foot of tremolite talc. Of 33 workers exposed to 52 million particles per cubic foot 10 showed signs of pneumoconiosis, 1 after 5 years 1 after 6 years, 2 after 9 years, 1 each after 11 and 12 years, 1 after 15 years, and 2 after 30 years or more of exposure; 1 man who had worked in talc for over 40 years had second-stage pneumoconiosis. In the group exposed to 4 million particles per cubic foot no definite cases of pneumoconiosis were observed.

From a study of granite cutters in New York City Smith (205) reports the following regarding length of exposure to dust and development of silicosis

> The average age in the negative group was 30 years. In the "increased-fibrosis", "questionable-silicosis", and "first-stage-silicosis" groups it ranged in the vicinity of 41 years; in the group showing second-stage silicosis it was 57, and in the group with evidence of tuberculosis and silicosis it was 50 years.
>
> Three of the men examined had been exposed under 5 years; these cases fell in the "negative" and "increased-fibrosis" groups. Three had been exposed over 50 years; these cases fell in the "second-stage" and "tuberculosis-with-silicosis" groups. Among the cases showing first-stage silicosis, more fell in the 20- to 29-year exposure group than any other, though 2 had been exposed less than 10 years. Among the cases with second-stage

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silicosis more fell in the 30- to 39-year exposure group than in any other. Among those with silicosis and tuberculosis the majority had been exposed from 20 to 39 years. The cases showing "questionable silicosis" were equally distributed over all exposure groups from 5 to 39 years.

The picture given is one of a slowly developing type of silicosis which may show its first stages after anywhere between 5 and 40 years and tends to become advanced with a marked tendency to be complicated with tuberculosis after 20 years' exposure.

The following statement from the Colliery Guardian, August 10, 1934 (206), gives additional data on the length of exposure required to produce silicosis and the average age at death:

Full particulars are available of 469 deaths from silicosis or silicosis with tuberculosis, in which there is no doubt as to the precise cause of death. In the 204 deaths from silicosis the average age at death was 54.3, and the average employment 34.3 years (2.3-60 years), whilst in the 265 deaths from silicosis with tuberculosis, the average age at death was 52.3 and the average duration of employment 31.5 years (2-67 years).

The relation of the amount of dust breathed and length of exposure to the development of silicosis is shown by the investigations of Bloomfield and Dreessen (207) in a granite quarry and by Pope (172) in the granite and foundry industries. Bloomfield and Dreessen (206) found that in the quarry industry pathological changes due to dust are limited to drillers--the only persons creating dust. The Leyner drillers and plug and jackhammer drillers working in the quarry holes were exposed to 144.4 and 112.1 million particles per cubic foot. Ten drillers showed signs of silicosis, half of those exposed 5 to 19 years had silicosis, and 4 of the 5 men exposed for more than 20 years were affected.

The following table prepared from Pope's report (172) shows the relation of amount of dust breathed and length of exposure to production of silicosis in the granite and foundry industries:

Dust Count	Weighted average of median dust counts, Million particles per cubic foot		Percentage having silicosis					
			Under 10 years		10 to 24 years		25 years or more	
	Foundry	Granite	Foundry	Granite	Foundry	Granite	Foundry	Granite
Group A	32	40.4	5.1	4.8	20.6	31.9	43.7	62.8
Group B	14	17.1	4.6	4.6	12.1	10.8	34.3	20.[illegible]
Group C	5	8.9	.7	6.0	5.6	11.1	25.9	6.[illegible]

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Section 2. - Determination of Dust in Air

The recognition of inhaled dust as the main factor in the production of pulmonary disease among miners drew attention to the quantitative aspects of the problem and the importance, as regards health, of determining the amount, weight, and particle-size frequency of the dust in air breathed by workers in various industries--especially those known as "dusty." Determination of dus also is becoming increasingly significant economically as evidence of the extent of the dust hazard involved in various dusty processes and as a measure of the efficiency of protective devices introduced to mitigate the hazard.

Determination of the dust content of the air by any of the more generally used methods entails the two processes of sampling and measuring the quantity of dust in the sample. Mavrogordato (208) classed the methods according to the nature of the sampling process--whether by precipitation (the konimetric or optical method) or by filtration (the sugar-tube or gravimetric method). Green (209) refers to two main types of methods used for sampling dusts: (1) Methods by which bulk samples of the dust are extracted from the air for weighing and chemical analysis, for example, the sugar-tube method; and (2) methods by which dusts are collected in a state suitable for microscopic examination, for example, the konimeter. After the sample has been collected the particles are counted, and/or the mass is weighed (209).

The ideal instrument (176) must be capable of efficiently sampling the dusty atmosphere with particular reference to particles ranging from 0.5 micron to 10 microns, and it should be possible, once this sample is obtained, to count the number of such small particles present; from the hygienic viewpoint the count is the best index of the extent of atmospheric pollution. Determination of the weight of the dust would also be valuable; but because it is virtually impossible to separate the particles under 10 microns in size from those over 10 microns and thus obtain the weight of the injurious particles (those capable of gaining access to lung tissue) and because one large particle may weigh many hundreds of times more than a smaller one, the weight of a given sample of dust should be used only as an additional guide in the interpretation of results, and then with some degree of caution.

The range in dust concentration over which determinations might be required is very great. Some atmospheres (those prevailing outdoors after rainstorms) contain very small quantities of dust, whereas the air of mines or abrasive factories often is highly polluted; therefore, the instrument must be capable of sampling both high and low dust concentrations with equal efficiency, an exacting requirement, as it means that the dust-collecting medium (whether water, sugar, or an adhesive) must not add greatly to the dust of the sampled air. The "control" or "blank" of the instrument must be low, and it must be uniform in dust content; in other words, a sample of the collecting medium must be so uniform that the analysis of a representative sample gives a true picture of the dust content of all of it used in a given series of tests.

As the dust concentration of air is changing continually, the instrument must be capable of sampling large quantities of air (176) to obtain a true picture of the condition. Once the sample has been obtained, the analysis

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should be as simple and rapid as possible; the more time-consuming and complex the method of analysis the lower its value. In many mines of the United States no electric power is available, and an instrument used for mine-dust sampling must be hand-driven; the instrument must be lightinweight and portable and of a size to permit introduction into a working place without interfering with the workers' movements.

To summarize, the final choice of an instrument for sampling dust depends on its efficiency, its small errors in analysis, its portability and weight, and on the difficulty or ease with which the samples obtained may be analyzed. The instrument or method should also be able to eliminate, as far as possible, variations or errors due to the "human equation"--a difficult requirement.

Dust-Sampling Methods

In general, dust-sampling methods can be grouped according to the physical principle utilized by the sampling instrument (176). This cannot be an exact classification because some instruments involve the use of more than one physical principle. The chief methods used for sampling aerial dust are: Condensation, filtration, washing, sedimentation, electrostatic, resistance, and impinging. Greenburg (176) gives the following historical summary of the various methods.

Condensation

In 1875 Coulier (210) showed that dust in air could be made visible by reducing the pressure within the containing vessel, causing the moisture in the air of the vessel to condense on the dust particles. He further showed that condensation might be prevented by filtration of the air through a layer of cotton wool. This principle has since been utilized by various investigators.

Aitken koniscope.--The Aitken koniscope, described by John Aitken in 1889 (211), consists of a metal tube and suction pump placed at right angles and joined by a connecting post. The metal tube, lined with hygroscopic material, is provided with a window at each end and a stopcock at the end distal to the point at which the pump is attached.

In operation the tube is held horizontally and the pump vertically, the observer looking through the window in the tube at the point of attachment with the pump. Air is drawn into the apparatus by means of the pump, and the stopcock is then closed. The air, more or less saturated with moisture from the hygroscopic material in the tube, is rarefied by depressing the pump once again. The dew point is thus lowered, with the formation of a fog or cloud due to condensation of the moisture on the dust present. The density of the cloud or fog is then compared with suitable standards and a qualitative estimate of the air dustiness established.

Aitken dust counter.--An improvement on the koniscope was devised by Aitken (212); this essentially makes use of the same principle as the koniscope, but an attempt is made to count the number of particles in the air. In its earlier form the instrument was large and nonportable. It consisted of a re-

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ceiver, an air pump, an air-measuring device, an illuminometer, and a gasometer. The air was drawn into the receiver by the gasometer. As it entered the receiver it was measured and mixed with a known quantity of dust-free air, saturated with water, and then rarefied by the pump. The rain, produced by condensation of water on the dust present, fell on the ruled, polished silver plate that formed the bottom of the receiver. The number of droplets on the counting plate multiplied by the proper factors for the amount of air sampled and the dilution with dust-free air gave a count of the number of particles present in the original sample. In addition to the disadvantage of being very large and nonportable manipulation is rather intricate and liable to large experimental and personal error.

Modified form of Aitken dust counter.--The modified Aitken dust counter, devised to overcome some of the drawbacks of the earlier instrument, consists of a hollow box with a ruled glass bottom and a plain glass top and is supported on two cylinders which open into it (213). One of the cylinders forms an air pump and contains the piston; the other cylinder is provided with three taps (stopcocks), the bores of which are of known volume. A plug of cotton wool is placed in the cylinder below the three taps, and the lower end of the cylinder is perforated so that air may enter. A mirror is supported beneath the receiver, and above it is a magnifying lens. Strips of damp blotting paper within the receiver saturate the air with moisture. By drawing down the piston when the stopcocks communicate with the cotton-wool chamber filtered air is drawn into the receiver. One of the taps (depending on the dustiness of the air to be sampled) is then turned at right angles to communicate with the outside air; it is then turned back again and the piston drawn down, bringing the sample of dusty air properly diluted with dust-free air into the receiver, where the dust is precipitated with the moisture in droplets on the ruled glass plate and the drops counted. Multiplication of the count by appropriate factors, as the volume of air sampled, gives a final figure for the number of particles of dust present in the original sample. This instrument is portable, being arranged on a tripod for field use. It has the disadvantage that the amount of air sampled is very small, and the opportunities for personal and experimental error are many. The most serious drawback is that all particles of dust receive equal significance, irrespective of size, since this method takes account of particles of ultramicroscopic size.

Hill diffractoscope.--The Hill diffractoscope (214) is essentially the same as the Aitken koniscope. The results are only qualitative, giving a rough estimate of the dust present by observation of the intensity of a beam of light directed into the window of the rarefied air chamber (Tyndall effect).

Jet dust-counting apparatus.--An adaptation of the principle of condensation is utilized in Owens' device (215), which he describes as follows:

> A high-velocity jet of air is caused to strike a microscope cover glass; the effect of this high velocity is to bring about a fall of pressure in the jet, accompanying which, and resulting from it, is a corresponding fall of temperature. This in turn causes a condensation of the moisture in the air upon the dust

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particles, which are thus projected wet against the cover glass, and, as the water evaporates, are left behind adhering to the glass.

In this apparatus the air is moistened by being passed through a chamber lined with moist blotting paper and is then drawn at high velocity through a slot about 1 cm long and 0.1 mm wide. After passing through this slot the air loses heat, and the moisture present condenses on the dust particles left on the microscope coverslip, forming the top of the cells. The coverslip is then placed under the microscope, and the particles are counted.

In his summary of the value from the viewpoint of industrial hygiene of the instruments designed to utilize the principle of condensation of moisture on dust particles Greenburg (176) states that those which permit a qualitative estimate only of the quantity of dust present have little practical value; those which permit the particles to be counted give results of limited significance because of errors in sampling and analysis and because of the difficulty of interpreting the counts, owing to the grouping of particles of ultramicroscopic size (which do not so far as is known constitute a health hazard) with those of a significant size from the hygienic viewpoint. The Owens apparatus yields high counts in normal indoor air; in very dusty atmosphere, however, the ribbon of dust on the microscope coverslip is so dense that counting the particles, even at high magnification, is difficult and often impossible.

Fehnel (216) mentions the following objections to the Owens jet dust counter:

1. The volume of sample, to be a fair, representative average, should be taken over a period of time because, except in a very few instances, the generation of dust is an intermittent process and is not constant.

2. The ribbon in the Owens jet counter sample does not have definite boundaries, and therefore counting the particles in a representative average band or integral part of the whole ribbon is very difficult.

3. The rate and efficiency of sampling with the Owens jet dust counter depend upon how rapidly the operator actuates the plunger. Also the washers are troublesome, and it is difficult to maintain the piston free of leakage.

4. It has been demonstrated that the Owens instrument is selective, sampling only particles of 6 microns and under.

Filtration

The principle of filtration has been applied to dust sampling in such various forms that only a few of these methods (176) need to be mentioned. In general, the air is filtered through cotton wool, cloth, paper, or a soluble chemical compound and the analysis made either by comparison with qualitative standards, by weighing, by counting the dust particles, and in some cases by both weighing and counting the dust.

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Cotton-wool method.--This method has been used by Arens, Cohen, Harcourt, Duckering, Cohen and Ruston, and Ditman (176). It yields only the weight of the dust in the air, and although it is a very valuable method for the estimation of toxic dusts (lead or arsenic) it is of limited value in determining the potentiality of a dust as a producer of pneumoconiosis.

Cloth method.--This involves the principle of filtration but utilizes cloth instead of cotton wool. Stacy (217) used cheesecloth squares, which were weighed before and after the dust was sampled; the difference was considered the weight of the dust caught. Hill (218) used weighed cloth filter bags placed in a conical metal holder and connected to an anemometer for measuring the volume of air sampled. The difference in weight before and after sampling was considered to represent the amount of dust in the quantity of air filtered. This method was cumbersome and inaccurate and required too much time for a single determination. An apparatus similar in principle is known as the American automatic dust filter (219); the air is filtered through a series of four or more specially woven cloth bags in a closed cabinet. The difference in the weight of bags before and after passage of the air is taken as the weight of the dust in the volume of air passed through the instrument. The deficiencies of this instrument are similar to those of the Hill bag method previously described. The Carrier dry-filter apparatus (220) attempts to keep the filter bags dry during the sampling period by heating the air with an electric heating unit before it passes into the filtration bags. Because of the high temperature involved Todd (221) utilized disks of Canton flannel, held in a special device. The air was filtered through the cloth, which retained the dust; the disk then was compared with a series of standard disks ranging from 1° to 10° of a rather arbitrary scale. With some of these methods it is possible to graduate or classify roughly various atmospheres in groups based on the amount of dust present; but even then Greenburg says (176) serious error from the hygienic standpoint is involved, for an atmosphere of many small particles (small enough to gain access to the lung tissue and hence injurious) may give a lower scale reading than an atmosphere containing a smaller number of particles of relatively less hygienic significance.

The Gooch crucible (176) has been used with some success; this apparatus usually is an ordinary porcelain or platinum Gooch crucible, the bottom of which is covered with a mat of shredded, acid-treated asbestos. The crucible is dried and weighed carefully, placed in a suitable holding device, and a known quantity of air drawn over it, after which it is again dried and weighed. The difference in weight is taken to represent the weight of the dust in the quantity of air sampled. The filtration surface is small, and if the mat is thick enough to retain the greater portion of the dust the resistance to air flow is very high, and therefore only a small quantity of air can be sampled.

Filter paper.--To overcome the objections to cloth filters and the Gooch crucible recourse has been had to filter paper for sampling dust. One of the earliest methods for the determination of dust by a filtration process was that of Rubner (176); a holder in which was placed a piece of filter paper was connected by suitable tubing to a water-jet pump. The volume of air drawn through the paper was measured by a gas meter in series with the pump and paper holder. The dust was estimated by comparing the filter paper with

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a standard scale. Filter paper has been used by Sargent (222), Moller (223), Hubendick (224), Johannsen (225), and Nesbitt (226). This method was used in Great Britain in studies conducted by the Advisory Committee on Atmospheric Pollution in 1916-17. An automatic apparatus was built by which 3 or 4 samples were taken each hour.

Paper thimbles.--Filter-paper thimbles have been used successfully in a number of dust investigations (173). The apparatus consists of a filter-paper thimble (similar to a Soxhlet thimble) and its holding device, by which the air is drawn through the thimble, and a meter for measuring the air. The thimble is dried in an oven and weighed before and after filtration, the difference in weight being taken as the amount of dust in the air sampled. Various grades of filter paper may range in efficiency from 63 to 90 percent when tested optically, using tobacco smoke as the test dust. The chief drawback from the hygienic viewpoint is that particles cannot be counted by the use of filter paper or filter-paper thimbles. Moreover, the utmost caution must be exercised in drying and handling the filter paper to avoid absorption of moisture and resulting errors in weighing. In an effort to overcome these objections many workers (179) have used another type of filtration method in which the air is filtered through a soluble chemical compound. After being sampled the substance is dissolved, and the amount of dust is determined both by weight and by count or by comparison with a scale of standards.

By Hahn's method (227) air is drawn through a filter of collodion wool and the quantity measured by piston displacement. After a suitable amount of air has been sampled the collodion is dissolved in ether, and the solution is then compared with a series of arbitrary standards.

The most successful method of this type, one utilizing granulated sugar to filter dust, was first employed by Frankland (228) and later by various others, including the Miners' Phthisis Prevention Committee of South Africa (229), Higgins, Lanza, Laney, and Rice (230), and Fieldner, Katz, and Longfellow (231). This method employs a sampling tube, in which a weighed amount (100 grams in the later types) of clean granulated sugar is placed. The dusty air is drawn through the tube by a pump or other suitable device. After a sufficient quantity of air has been sampled (usually 15 cubic feet) the sugar tube is taken to the laboratory for analysis. The sugar is dissolved in hot water, and count and weight determinations are made on the dust present.

Fieldner and his coworkers (231) found the efficiency of the sugar tube to be approximately 55 percent when it was tested optically with tobacco smoke and about 87 percent when tested gravimetrically with silica dust. These results would indicate relatively high filtering efficiency. Both weight and count of the number of insoluble and noncombustible dust particles present in a given atmosphere are obtained by this method. It has the disadvantage that a large and variable quantity of dust is present originally in all samples of sugar; it therefore cannot be used effectively for sampling either soluble or inflammable (combustible) dust.

Washing

Washing methods have been applied to the sampling of insoluble dust with much success (176). These methods, in general, bubble the dust-laden air

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through water to the dust and bring it into suspension. The amount of dust present may be estimated by weight and count.

Palmer dust apparatus.--This apparatus was devised in 1916 (232). It is a pear shaped glass bulb, at the base of which is a water trap so arranged that the air is drawn through the trap (preferably at a rate of 4 or 5 c. f. m.) and breaks the water into spray which washes the dust from the air. After a suitable quantity of air has been sampled, depending on its dustiness, the water is drained from the trap and taken to the laboratory for analysis. By this method both weight and count determinations may be made of some kinds of dust.

Variations of the washing methods have been devised by Meyer (233), Read (176), and Drinker (234). The main difficulty with washing methods, according to Greenburg (176), lies in the inability to wet very small particles of dust in the brief interval requisite to sampling large volumes of air. One obvious advantage of this method over the sugar-tube method is that the water used, if properly distilled, contains little or no dust, while the sugar in the sugar tube method, no matter how carefully prepared, always contains a large and variable quantity of solids.

Sedimentation.

In 1879 Miquel (235) described a method of collecting dust by allowing it to settle on plates. The particles were counted under a microscope. In 1880 Tissandier (236) substituted sheets of paper 2 meters square for the glass of Miquel. The paper was supported horizontally, and after a suitable time the dust was collected by a small brush and examined under the microscope. In 1902 Irwin (237) estimated the dust in Manchester air by collecting a volume of snow 100 square inches in area and 1 inch in depth. The snow was melted and filtered and the residue dried and weighed. Liefman (238) utilized two oil-coated disks on a revolving vertical shaft, one supported horizontally and the other vertically. A vane keeps the vertical disk facing the wind; this disk collects some dust by impaction, while the horizontal disk collects the dust deposited by sedimentation. The dust laden oil is removed from the plates by ether, and after evaporation the dust is again suspended in 5 cc of oil. The final suspension is compared with a series of standards made by mixing various quantities of soot and oil. This method allows only a rough quantitative estimate of the dust present in the atmosphere.

Des Voeux and Owens (239) used an enameled iron vessel 2 square feet in area arranged somewhat like a large funnel. The dust was washed down into a bottle beneath the funnel by rain. The Advisory Committee on Atmospheric Pollution of the Meteorological Office of Great Britain also used this method. Hill (218) used porcelain evaporating dishes; Mitchell (240), rectangular glass plates coated with vaseline and placed on poles 25 or 30 feet above the street level; and Whipple (241), 2-quart tin pails coated inside and out with resistant varnish and suspended on poles about 20 feet above the street level. This method does not sample the air but permits an estimate of the quantity of dust that settles on the surface of the water.

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Gravity settling methods, in general, do not indicate just how much dust a given sample of air contains but aid in estimating the amount of dust falling on and adhering to a given surface, either oiled, wetted, or dry, in a given period.

Green (242) describes accurate sedimentation methods for determining the number and size-frequency of particles in dust clouds. The containing vessel for the sedimentation cell is a brass cylinder 5 cm deep, and 3.6 cm in diameter; it can be closed at the top by a swivel lid and at the bottom by a brass slide in which two $\frac{1}{2}$-inch coverslips are mounted, thus enabling a known volume of cloud to be trapped in an airtight space. The coverslips are slipped into holes in the underside of the slide and lie almost flush with its upper surface, being pressed firmly against a narrow rim at the top by means of ebonite disks held in position by swivel springs.

The instrument may be operated either directly by hand or indirectly from outside a dust chamber. In the first instance it is waved, with the axis of the cylinder vertical, up and down through the air; when a representative sample of air has been entrained the lid and slide are pushed over the ends and the cylinder left in a vertical position 1 to 3 hours. In the second instance the instrument is fixed in the dust chamber to permit free access of air to the cylinder, and the dusty air is circulated through it by an electric fan placed horizontally underneath. The lid and slide are pulled into place from outside the chamber by suitable strings. The lower limit of particle diameter detectable by this method is about 0.2 micron.

Green (242) emphasizes that the methods described are intended for research, for measurements of dust in fairly high concentration, not for routine or long-period estimations. The methods also provide a simple and accurate means of testing in the laboratory the efficiency of dust-sampling apparatus. They are most suitable for clouds containing not less than 1,000 particles per cubic centimeter, although they can be extended to clouds containing not less than 100 particles per cubic centimeter; they cover the whole size range down to 0.2-micron diameter. Green also describes methods for counting the particles under a microscope of high resolving power and for determining rapidly the size-frequency of particles by a comparator.

In an article on recent developments in methods of sampling dust Green (209) said that it is somewhat disconcerting to find in the literature dealing with the hazard due to mineral dusts a general lack of information about the intrinsic nature of the dusts as they exist in the air. He attributes this to the lack until recent years of accurage methods for gaining this information, although it is true that many data have been accumulated as a result of determinations with field instruments, but the value of these figures must be discounted owing to inherent defects in the instruments themselves. He gives a critical review of the available instruments and a method of testing them, including a method of generating in the laboratory dust clouds similar to those found in industry. Three types of instruments were selected for testing--the Greenburg-Smith impinger, the "standard United States instrument"; the konimeter, in general use in South Africa; and the Owens jet dust counter, often used in England and many other countries. He concludes that none of these instruments

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would give accurate date about either the number or size-frequency of particles in dusts, nor could they be used for fundamental work, and for comparative work they would need very careful preliminary calibration in the laboratory against dust of similar character to those found in the industry under investigation. He and his coworker Watson developed a modified thermal precipitator which they claim satisfies most of the requirements of a standard instrument for both fundamental and comparative work; it yields accurate information about the number of particles and their size frequency and, to a certain extent, about their shape. A fundamental investigation would also require that the nature of the particles be determined quantitatively; the thermal precipitator records can be mounted for petrological examination, but owing to the difficulty of identifying the nature of particles below about 2 microns in diameter this part of the problem still awaits solution.

Electrostatic Methods

The fact that electrically charged bodies in an electric field tend to migrate to one of the electric poles has long been known (176). This principle of the precipitation of suspended matter by electricity has been applied commercially to the collection of industrial dusts by Cottrell (243), who reduced to engineering practice the fundamental processes developed by earlier investigators; adaptation of the Cottrell process to determination of dust in air is under consideration by engineers interested in dust control. In 1919 Bill (244) reported the use of the electrostatic method for sampling dust in air. The essential feature of this instrument is a collecting electrode, consisting of a metal tube, and an ionizing electrode. The dust particles are charged by the ionizing electrode and travel to the collecting electrode, where they are deposited. The collection system, however, is only a small part of the complete apparatus. In addition, it includes a high-tension transformer, a rectifying device for the high-potential alternating secondary current, a source of alternating current to excite the transformer, and a pump or fan for passing the air to be studied through the electrically charged field.

In 1923 Drinker, Thompson, and Fitchet (245) described a greatly simplified form of electrostatic apparatus having a dust-removal efficiency of nearly 100 percent. In 1925 Drinker and Thompson again simplified this apparatus (246). Current is supplied by four alkali storage cells, from which both the precipitator and suction-fan motor derive the necessary current. The entire apparatus weighs approximately 13 pounds and appears to be an instrument with considerable practical application (176).

Resistance

This method makes use of the fact that the resistance of a filtering medium increases as its pores become filled with dust. The apparatus, known as the "Anderson and Armspach Dust Determinator" (246), consists of a holder in which a piece of filter paper or other porous fabric is clamped. Air is drawn through the paper at a constant rate and the difference of pressure between the two sides of the paper is determined by a U tube, the arms of which open into the holder, one on each side of the paper. The manometer reading

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indicates the difference of pressure existing between the two sides of the filter. As the paper clogs more pressure is required to keep the air passing at the same rate, and the manometer reading increases. This instrument was developed for use in testing air washers by the research laboratory of the American Society of Heating and Ventilating Engineers. It has no hygienic purpose because it gives no information on particle size and quantity of dust encountered. The correlation between the actual dust content of the air and the resistance to passage through a filter paper would entail considerable time and arduous labor, if it could be done at all.

Impinging Methods

Another method impinges a definite sample of air on a prepared surface. This apparatus has the advantage that a definitely known volume of air is sampled, and by the velocity of the impact a greater percentage of the dust is caught and may be estimated. Numerous variations of impinging the air on prepared surfaces have been developed, most of which have not been highly efficient.

Konimeter.--In 1916 Kotze (248) called attention to an instrument which he called the konimeter. This consists of a chamber, one side of which is a vaseline-coated glass plate, and an impinging orifice, which is perpendicular to the slide. The air is sucked out of the chamber by a cylinder and a spring-actuated piston. The only means of ingress of air is through the impinging orifice, and when the air enters the chamber at high velocity in this manner the dust is deposited in the form of a spot on the greased plate. The dust may be counted under the microscope, using a ruled eyepiece. The method of examining konimeter dust spots by opaque illumination, as practiced until recently in South Africa (249), not only gave unreliable but also misleading results and has been replaced by examination of the dust spots under transmitted polarized light.

Hill dust counters.--Hill (214) devised two forms of dust sampling devices that use the impingement principle. The first, the photographic dust counter, consists of a metal frame supporting a metal funnel at one end and at the opposite end a photographic plate holder. An anemometer is placed in the funnel-shaped opening and a moistened photographic plate in the plate holder at the opposite end. Air is forced through the anemometer against the plate. After the usual photographic development the particles on the plate may be counted directly, or a print may be made and the particles enumerated. This method obviously has the same disadvantages as the other low-velocity impingement methods, to which is added the error introduced by the use of the photographic method.

Hill's (214) second instrument of the impinger type consists of a hand-actuated piston moving in an air cylinder, the only inlet to which is a nozzle one eighth inch in diameter. In front of this nozzle and fixed only a short distance from it is a microscope cover coated with an adhesive preparation. When the piston is drawn out a jet of air is impinged on the prepared slide, which catches the dust. By using 6 slides in series Hill found that the first slide caught only 62 percent of the dust. He assumed, however, that all the

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dust was caught by the 6 slides, an assumption considered fallacious. This instrument is similar to the Kötze konimeter. Comparatively high velocity is necessary for deposition of dust in this manner.

Impinger dust-sampling apparatus.--In a comparative study by the United States Bureau of Mines and the United States Public Health Service (250) the dust-catching efficiency of the impinger was found to be high. Consequently its physical principles and characteristics were made the object of a special study; as a result a relatively satisfactory and fairly practical form of dust-sampling instrument, based on this principle, has been evolved (251). This device has the advantage of high dust-catching efficiency when air is sampled over the full range of dustiness (from relatively pure outdoor air to that found in very dusty coal-mining operations) at the relatively rapid rate of 28.3 liters (1 cubic foot) per minute. The dust is caught in a liquid medium in which it may be counted and analyzed microscopically, gravimetrically and chemically (provided it is insoluble in water). Three forms of the instrument are described: Electrically driven, compressed-air-driven, and a hand-actuated form.

While using the impinger apparatus in a study of the hazards of rock drilling on building and subway construction work about New York City Fehnel (216) experienced difficulty in checking with the empirical method found effective by the United States Public Health Service in its study of the granite industry. He consulted other technicians and found that some modified the light by tilting or shading the mirror; he therefore tried a modification of the illumination. Other investigators, manufacturers of microscopical equipment, and microscopists who were consulted agreed that the standard procedure did not reveal the small particles, and the use of dark-field illumination was essential. Various combinations of magnifications and dark-field illuminations were demonstrated at Saranac Lake in April 1932, using a specially prepared silica dust of 3-micron average size. It was decided at that time that the various agencies interested would employ both light- and dark-field methods in studying various industrial dusts. So far, according to Fehnel (216), no attempt has been made to correlate the findings collectively. Two comprehensive studies employing both methods of counting showed a fair, consistent relation between counts on the same types of dust, so that it is possible to establish a conversion factor. The modified method has proved that technicians can check fairly consistently their own and others' counts on the same samples; moreover it reduces materially the time element necessary.

Fehnel (216) also calls attention to the value of determining particle-size measurements with dust counts. His first method employed the filar micrometer, using a dry preparation made by evaporating the sample collected in the impinger and examining under oil immersion. As such a procedure is very laborious, Green's method (252) of determining the particle size of paint and rubber pigments was adopted; this method requires more operations but eliminates the possibility of becoming mechanical when doing routine work, as is the case with the filar micrometer. It also speeds up materially the work of particle-size determinations. The percentage frequency of occurrence is plotted against particle size on Hazens' logarithmic paper, so that the curve

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comes out a straight line, which makes it easy to interpolate. Fehnel (216) states that the interesting facts found so far on particle sizes are that the median or 50 percent of the industrial dusts studied are in the 1- to 3-micron size range and that 90 to 99 percent are less than 10 microns.

According to Hatch and Thompson (253), the impinger technic has provided valuable assistance in the study of the dust hazard, but because of the considerable amount of apparatus involved and the skill required in the quantification of samples it is not entirely satisfactory for routine plant control. Given a standard of permissible dustiness with a reasonable factor of safety, it may even be sufficient for routine plant control to know whether the dustiness associated with a particular process is above or below the standard; the ability to obtain this information quickly is more important than the accuracy of the determinations. As Mavrogordato (208) has pointed out, the plant operator does not want precise dust counts but rather data on which he can act. Because of the skill required in operation of the apparatus or in "quantification" of samples or because of other undesirable characteristics, the impinger, direct-vision konimeter, and other rapid methods of dust determination were not considered entirely satisfactory for the average industrial plant. A new method developed by Hatch and Thompson (253) appears to have many desirable features with respect to simplicity and rapidity in operation. An Owens counter, modified to permit the collection of eight samples direct onto a single glass slide, is used as the sampling instrument, and the "dust ribbons" are quantitated by matching against a series of standard ribbons under a comparison microscope. The method is calibrated in terms of the impinger. It is intended for rapid, approximate dust determinations only and is not proposed as a substitute for the impinger. It must be calibrated at the outset against that instrument, and the relationship should be checked from time to time. Data obtained with the Owens counter alone should not be regarded as constituting complete "legal" evidence of dust concentrations. As an adjunct to the impinger it may be used to measure the efficiency of dust-control equipment.

Modified Zeiss konimeter.--Since dust diseases are due to the physical or chemical action of certain dusts below a specific fineness it is desirable to measure independently the content of the finest dust particles in suspension in air without at the same time being burdened by the coarser and relatively harmless grains. This principle of selective dust estimation has been applied in the Zeiss konimeter (254). In this apparatus a sample of air is taken and all dust particles above a certain size are removed by filtration; the finest particles remaining in suspension are then deposited on a slide in the usual way. The apparatus consists of the standard Zeiss konimeter, supplemented by a special air filter, and a small pump to aspirate air through the konimeter. The air enters the sampling unit at the filter, which contains a number of glass beads, and passes through a narrow jet. The sampling disk is the same as in the original Zeiss konimeter, a glass disk secured in a ring, which can be turned about the konimeter to the 30 sections on the slide opposite the sampling jet in succession; up to 30 individual samples can thus be taken without dismantling or readjusting the whole apparatus. The electric motor is of standard design and can be run from batteries or from a direct-current supply.

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The dust samples are examined in the usual way under a microscope, all particles being visible at the outset. After a preliminary examination a drop of tetralin added to the sample renders the quartz particles invisible, as their refractive index is virtually identical with that of tetralin. By a differential count it is possible to estimate the quartz content of a dust sample. The article mentions that this apparatus has been exhaustively tested in various dust researches in Europe and found to give reliable and reproducible results.

Comparative tests made with the Kotze and Zeiss instruments (255) under identical conditions revealed that the Zeiss has an efficiency 50 percent higher than the Kotze; therefore, in making determinations with the Zeiss konimeter the limit of safe concentration is increased from 300 to 450 particles per cubic centimeter.

Photometric estimation of konimeter dust samples.--In the November 1934 issue of Mining Magazine Franks and Tresidder (256) described a rapid photometric method of estimating the dust collected on treated konimeter slides; this method retains all the advantages of the konimeter and at the same time overcomes certain disadvantages--notably, those associated with counting the material in the dust spot. Counting is arduous and time-consuming; photometric estimations can be made in about one tenth the time required to count an average spot. Furthermore, according to Frank and Tresidder (256), the counting method is a purely arbitrary measure of the dangerousness of dusty air; equal value is placed on each particle, regardless of its size or siliceous nature. The photometric values are most sensitive to the size range that is most dangerous; this method also tends to differentiate the particles by giving high value to quartz and largely obviates errors in counting due to sector sampling, aggregation, fatigue, and personal error. The estimable range of dust concentration is extended to include dust concentrations found in blasting. Such a method should readily give data which, when correlated with clinical findings, should lead to a better identification of the dust hazard.

Physiological Methods

In addition to the above methods of determining the quantity and composition of dusts that occur in many industrial occupations it is important to distinguish those capable of causing pneumoconiosis. The obvious way to determine whether a substance can affect the human lung is to test its action on the lungs of animals, but according to Kettle (257), this method is not altogether satisfactory as it is laborious, expensive, and, above all, time-consuming. Whatever the technic employed for the introduction of dust into the lungs, all who have worked on experimental pneumoconiosis agree that the end lesion--the characteristic fibrotic nodule--cannot be produced in a few days or weeks but only in periods measurable in years rather than months; the method therefore has little value as a practical test. Kettle (257) divides the constituents of occupational dust into two groups--the active and the inert--according to their behavior when injected into the subcutaneous tissues; this grouping corresponds with clinical and industrial experience. The active dusts cause an acute inflammation with necrosis of tissue and

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subsequent fibrosis, whereas the inert dusts give rise to nothing more than a mild and transient reaction. Further, if animals in which such lesions have been produced are infected intravascularly with tubercle bacilli clear evidence is obtained that the active dusts determine a local settlement and proliferation of the bacilli out of all proportion to that seen in the tissues generally and in the reactions surrounding the inert dusts. This technic provides a method for testing the capacity of a dust to modify an infection; however, Kettle (257) states that the claim that it tells whether the same substance can produce fibrosis of the lung is perhaps less legitimate, as there is an obvious difference between the injection of a substance into the tissues, with all the trauma involved, and its introduction into the lungs by the natural routes. He has found, however, that particulate matter suspended in normal saline may be injected directly into the lungs through the trachea without producing undue trauma to the pulmonary tissues. Particles introduced into the lungs in this way are picked up by phagocytes just as are the particles of dust inhaled in the air, and in due course some of the dust containing phagocytes reach the extrapulmonary lymph nodes. In human silicosis the earliest lesions are found in the root glands as the result of this process; the same is true in experimental pneumoconiosis. It does not matter how the dust reaches the lungs; although the mode of introduction possibly may have some relation to pulmonary lesions obviously it can have no influence on the glandular deposits produced entirely by natural means.

Kettle (257) found in his experiments a striking difference in the reactions occurring in the extrapulmonary lymph nodes according to whether the material introduced into the lungs was an active or an inert dust. If the injected dust was inert it remained in the substance of the pulmonary lymph nodes without causing tissue reaction and without exciting the attention of other phagocytic cells. If the dust was active, as soon as it was liberated by the death of the phagocyte it was ingested by fresh cells which appeared in such numbers as to disorganize completely the structure of the node. This activity was progressive and eventually led to the formation of the characteristic acellular nodule, although it might take a year or more. However, Kettle found it was necessary to wait for the end lesion to form in the lymph nodes before he could reach a conclusion regarding the nature of the dust; within 3 months a microscopic examination revealed such significant changes as to make diagnosis possible. The Colliery Guardian (258) points out that application of the method on a large scale might result not only in a definite preliminary classification of dusts but in the establishment of standards by which any samples could be tested.

In an investigation of the cellular response of lymph nodes to various dust suspensions introduced into lymphatics Stüber (259) found that cellular response of the lymph nodes to the injection of dusts containing considerable free silica is essentially different from that to other particulate material, the latter being phagocytosed only by normal lymph phagocytes. Some silicates produced a stimulation at the beginning with later slight changes in the cytoplasmic structure of the host cells. He described the response of the phagocytic system of lymph nodes to the injection of silica and the characteristics of the silica-containing phagocytes; these are identified biologically as

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modified endothelial lymph phagocytes. The silica-containing cells lose much of their phagocytic power toward other particulate matter. Phagocytes that answer the description of the silica-containing cells in lymph nodes as produced in these experiments could be found in air spaces in cases of experimental as well as industrial silicosis of the lungs. It appears possible that the lymph-node injection method may be developed into a rapid means of determining the toxicity of certain dusts.

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